FACULTY OF ENVIRONMENTAL SCIENCES AND PROCESS ENGINEERING

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Topic:

Climatic Change Impacts on Subsistence Agriculture in the Sudano-Sahel Zone of Cameroon - Constraints and Opportunities for Adaptation

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by

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Dedication

I am wholly indebted to my mum (Ngekwi Magdalene) and my late dad (Bah Fritz Techoro), for making me what I am today. They bore me, raised me, and supported me, in the hardest of times. To them I dedicate this work!

And also to you, Naomi Helena Azanui→ ***" Mih nkogeh woh"***

Abstract

Unlike many areas of the world where agricultural producers exhibit the physical, economic and social resources to moderate, or adapt, subsistence agriculture in the Sudano-Sahel region of Cameroon is seem to be particularly vulnerable to the impacts of climatic variability. This is in part due to the fact that the majority of the population depends on rain-fed agriculture for their livelihood. Adapting to climate change in the subsistence agricultural sector is therefore very imperative in providing food security and concomitantly protecting the livelihood of rural communities. This study examined the patterns of current climatic variables on some selected subsistence staple crops namely; millet and sorghum in the Cameroon´s Sudano-Sahel. It also valorized and documented the community based adaptation strategies used by local farmers to cope with current climate change, explored the constraints and opportunities in adaptation and mitigation that could facilely be integrated and incorporated into policies and programs. The guiding premises were that climatic change impacts subsistence crop yields as the lower the rainfall, the higher the vulnerability of the yields of staple crops. It also hypothesized that the present community-based strategies used by the local farmers are relevant and crucial to the present day quest for climate change adaptation strategies. Analyses of agricultural droughts using the Standardized Precipitation Index (SPI), spatio-temporal land use and land cover dynamics via remote sensing were utilized as well as the application of statistical tools for the investigation of pressure and state indicators. A participatory research approach was used in exploring adaptation patterns perceived by the ruralites in the face of variable climatic condition via administered questionnaires. The results suggested critical impact asymmetries due to climatic and socio-economic factors affected subsistence crops in the Sudano-Sahel of Cameroon. Furthermore, SPI results indicated incidences of droughts; with the Multilinear Regression (MLR) models showing temperature and rainfall to an extent determined agricultural crop productivity in the Sudano-Sahel. However, other factors such as population growth have undoubtedly caused enormous impacts on the agricultural system as seen in remote sensing analyses. Questionnaire survey findings also connoted that subsistence farming communities have a rich repertoire of strategies ranging from changing of planting dates, changing of crop varieties, switching from crops to livestock, use of local indicators, movement from rural to urban areas, increment in cultivated lands, irrigation soil conservation practices among many others as they perceive varying climatic conditions. Additionally, some of these indigenous strategies are inherent in ecological agricultural practices that offer a win-win scenario for the simultaneously tackling of climate change adaptation and mitigation and hence meeting the development goals. The results further highlighted the lack of money, poor access to climate information, the encroachment of desert and shortage of man power as some of the factors hindering subsistence farmers' ability to adapt. The study concluded that adaptation measures in subsistence agriculture were highly significant for poverty reduction, thus improving on the well-being of the ruralites. The key to the ability of farmers to adapt would be access to relevant knowledge and information. Following the rich repertoire of strategies by local farmers, adaptation needed to be mainstreamed and institutional networks strengthened in order for effective community based adaptation.

List of abbreviations and acronyms

AR4	Fourth Assessment Report
€	Euro
C	Carbon
$C_6H_{12}O_6$	Carbohydrates
CDM	Clean Development Mechanism
CH_4	Methane
cm	centimeter
COP	Conference of Parties
GDP	Gross Domestic Product
GHG	Greenhouse Gases
$GtCO_2eq$	Gigaton carbon dioxide equivalent
GWP	Global Warming Potential
ICRISAT	International Crops Research Institute for the Semi-Arid-Tropics
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convengence Zone
km	kilometer
LDC	Less developed countries
Max.	maximum
MDG	Millennium Development Goals
MFIs	Microfinancial Institutions
Min.	Minimum
mm	Millimeter
mm	millimeter

$MtCO_2eq$	Metric ton carbon dioxide equivalent
N_2O	Nitrous Oxide
NAPA	National Adaptation Programs of Action
^oC	degree Celsius
%	percentage
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
SA	Sustainable Agriculture
SODECOTON	Société de développement du coton du Cameroun
SPI	Standardized Precipitation Index
SSA	Sub-Saharan Africa
TAR	Third Assessment Report
Temp.	Temperature
tha^{-1}	tons per hectare
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Adaptive capacity – The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (UKCIP 2003).

Climate Change – Refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC TAR2001).

Coping Capacity – The means by which people or organizations use available resources and abilities to face adverse consequences that could lead to a disaster. (In general, this involves managing resources, both in normal times as well as during crises or adverse conditions (IPCC TAR2001).

Extreme event – An extreme weather event refers to meteorological conditions that are rare for a particular place and/or time, such as an intense storm or heat wave. An extreme climate event is an unusual average over time of a number of weather events, for example heavy rainfall over a season (UNFCCC 2006).

Resilience – Resilience is a tendency to maintain integrity when subject to disturbance (UNEP 1998).

Sensitivity – Is the degree to which a system is affected, either adversely or beneficially, by climate related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise) (IPCC TAR 2001)

Vulnerability – The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC TAR 2001).

Climate Change – Refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC TAR 2001).

Climate Variability - Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). See also climate change (IPCC TAR 2001).

Climate Impact Assessment – The practice of identifying and evaluating both the detrimental and beneficial consequences of climate change on natural and human systems (IPCC TAR 2001).

Technical Mitigation Potential–is the theoretical amount of emissions that can be reduced and the amount of carbon that can be sequestered given the full application of current technologies, discounting implementation costs. The technical potential describes the magnitude of mitigation allowed by current methods, and does not provide realistic estimates of the amount of carbon that will be reduced under current policy and economic conditions (IPCC 2007).

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1. Introduction

1.1 Background

Climate change is nowadays recognized as one of the most challenging and complex problem facing the globe. The stakes very high and the impacts would add significantly to the development challenges of ensuring food security and poverty reduction in most Sub-Saharan African countries in general (Watson 2001) and the Sudano- Sahel of Cameroon in particular. This is a region in the world that has become poorer in the last generations (Ravallon and Chan 2004). While human population globally is growing by 3% per annum and 2.6% in Cameroon, the yields of major food crops grow at just a percentage (Inter-Academy Council 2004).

Climate change affects agriculture in several ways, one of which is its direct impact on crop productivity (Ziervogel et al. 2006) and as a consequence hindering the prospects of achieving some of the Millennium Development Goals (MDG): to eradicate poverty and hunger; health improvement and sustainability (UNDP 2010). Several factors have contributed to the deepening poverty and underdevelopment. These include the difficulty in coping with climate variability in a continent subjected to frequent droughts, floods, extreme high temperatures and land degradation. In addition, various socioeconomic, demographic, political, institutional, and policy trends have limited the abilities to adapt to climatic variations (Rosenweig and Hillel 1998; Adger et al. 2007)

The African continent as a whole contributes very little to global climate change, with low carbon dioxide emissions from fossil fuel use and industrial production in both absolute and per capita terms. It accounts for 2–3% world's carbon dioxide emissions from energy and industrial sources, and 7% when the emissions from land use (forests) are taken into account (Darwin et al. 1995). These greenhouse gases (GHG) emitted have been identified as the prime cause of global warming. Ironically it is these poor countries and people who have contributed least to the problem of climate change; due to their very low greenhouse gas emissions who suffer most from its consequences. Even if emissions are severely curbed, climate change will still occur. The IPCC latest reports (AR4) states clearly that climate change is already having discernible impacts. It is disproportionately affecting poor communities- especially the poor countries, with the Sudano-Sahel region of Cameroon being part of it painting a devastation picture of what will happen if immediate actions were not taken into consideration. According to the report that enjoys an overwhelming scientific consensus, Africa will be particularly hit hard by droughts and water scarcity, thereby undermining food production, increasing hunger and dislocating communities across the continent (IPCC 2007). The vulnerability of the population is simply due to the fact that the majority of African community population depends on subsistence agriculture for their well-being (FAO 2003). Climate is a primary determinant of agricultural productivity and any adverse changes in it would likely have devastating effects in this sector causing crop failures and concomitantly affecting the livelihoods of the majority of the population that hinge on rain-fed agricultural practices for their mainstay, accounting for about 97% of the agricultural land (Calzadilla 2009).

Community based adaptation is capable of reducing the vulnerability as well as improving on the resilience of the local people to climatic variability and change. Although subsistence farming thus far have a long history of coping and adapting to some of these changes, effective adaptation strategies and actions should therefore be aimed at securing the well-being of the subsistence farmers in the face of climatic changes. However, until recently, most adaptation efforts have been top-down, and little attention has been paid to communities' experiences of climatic variability and their efforts to cope with their changing environments. The top down focuses on multi-decadal global climate predictions involving quasi-linear responses dominated by increases in greenhouse gases which are downscaled to societal environmental impacts (Solomon et al.2007). Adaptation strategies should be geared towards a blend of the top-down and bottom-up platforms; starting from a sequence of analytical steps in the physical vulnerability, moving through the biophysical impacts and terminating at the socio economic response to climate which tend to be location specific (Dessai and Hulme 2004). Effective adaptation strategies aimed at securing the well-being of subsistent farming communities requires the involvement of multiple stakeholders ranging from policy makers, extension agents, Non-Governmental Organizations (NGOs), researchers, communities and to a greater extend the subsistence farmers.

1.2 Problem statement

Agriculture plays a very important role in the livelihood of the communities living in Cameroon accounting for more than a third of the country's GDP. Having a well-watered southern region, the northern region is semi-arid and falls within the Sudano-Sahel of Africa. The majority of the 6.5 million inhabitants living in Cameroon´s Sudano-Sahel depend on rain-fed agriculture for their subsistence (Molua and Lambi 2006).

The availability of food depends on agricultural production. Yearly-seasonal and geographical crop yield availability depends on space and timely rainfall distribution. Climate is a primary determinant of agricultural production and any adverse changes in climate would likely have a devastating effect on this sector thus threatening crop failures. Such changes would concomitantly affect the livelihood of the majority of the population since they hinge on rain-fed agriculture for their mainstay where about 97% of the agricultural land is used. Despite the reliance of the large proportion of the population on agriculture, agricultural development has historically not been a priority of the governments, with 1 or less of the average national budgets going to agriculture, particularly commercialized agriculture. (FAO 2003). Ironically, subsistence agriculture that accounts for the bulk of agricultural type practiced has been relegated to the backyard.

Issues on climate are only marginally entering into the development planning in the northern region of Cameroon and societal resilience so far is not improving. Most climate change impacts research studies have been focusing on commercial crops while impact studies of climate change on subsistence staple crop production remains a poorly investigated area in research. These partial assessments, most often consider climatic change effects in isolation, providing little insight into the level of awareness of the local farmers on the issue, what and how they are doing to cope with the changes. Subsistence agriculture in the Sudano-Sahel is highly dependent on climate variability (Salinger et al.2005) with prolonged droughts being one of the most serious climatic hazards affecting the agricultural sector.

Adaptation to climatic variability and change is not a new issue, but the idea of incorporating the present and future climate risk into policy-making is. Although subsistence farming thus far have a long history of coping and adapting to some of these changes, effective adaptation strategies and actions should therefore be aimed at securing the well-being of subsistence farmers in the face of climatic variability. The importance of indigenous local knowledge in the facilitation of adaptation to climate change within rural subsistence communities cannot be underestimated. Community based adaptation is thus capable of reducing vulnerability as well as improving on the resilience of the local people to climatic variability and change. However, until recently, most adaptation efforts have been top-down, and little attention has been paid to communities' experiences of climate change and their efforts to cope with their changing environments.

Adaptation strategies should be geared towards a blend of the top-down and bottom-up platforms; starting from a sequence of analytical steps in the climate system, moving through biophysical impacts and terminating at the socio economic response to climate which tend to be location specific (Dessai and Hulme 2004). Effective adaptation strategies aimed at securing the well-being of subsistent farming communities requires the involvement of multiple stakeholders ranging from policy makers, extension agents, NGOs, researchers, communities and to a greater extend the subsistence farmers.

1.3 Research questions and hypotheses

In order to address the pertinent issue heightened above, the following research questions are raised and accompanied by some adopted hypothesis.

1. To what extent has the recent climatic variability and change influenced the yields of some subsistence crop produced in the Sudano-Sahelian zone of Cameroon?

2. How do subsistence farming communities respond to climatic variability and change? This particularly question makes an in-depth into: - what are the responses? What are the constraints? How can the constraints be overcome? And how important are the constraints?

The research **hypothesizes t**hat:-

1. Climatic change impacts subsistence agriculture in the Sudano-Sahel of Cameroon, as the lower the rainfall, the higher the vulnerability of the yields of subsistence crops.

2. It is hypothesized that the community based adaptation strategies presently in used by the subsistence farmers might be relevant to the modern approaches towards adaptation. The current Community based adaptation strategies are thus positioned as important entities that could be improved, strengthened and sustained for use in development assistant projects.

1.4 Objectives of study

The overarching goal of this research is to gain a better understanding of climatic change impacts on some subsistence crops; and how subsistence farmers have responded and adapted to these changes in the Sudano-Sahel of Cameroon. Drawing lessons from the past with the objective of understanding current situations and providing data base information for policy making.

The specific objectives are to:-

1. Examine the patterns of climatic variable on subsistence crops in the area of study

2. Understanding the local peoples´ perceptions towards recent climatic variability there by identifying the indigenous adaptation practices used by farmers in the area of study. Identification of factor influencing the adoption of adaptation strategies and as such constraints and opportunities in adapting to the effects of climate change.

3. An attempted valorization of the strategies used by subsistence farming communities in surviving and prospering in times of adverse climatic conditions are made and the contribution to the integration of local knowledge in climate change adaptation strategies at different levels.

4. Document and generate climate change adaptation strategies for subsistence farming communities in the Sudano-Sahel that could be integrated into the government policies.

1.5 Research rationale

The image portrait by Sudano-Sahel region of Cameron is poverty, famine, drought and desert encroachment. The region is home to the poorest people living in Cameroon and with a population of over 6.5 million inhabitants, two third are rural and based on the poverty line of a dollar per day, 82 percent of the rural inhabitants are poor (Nguetse 2009). Although about 50 percent of the land is degraded and not suitable for cultivation, the majority of the population depend on subsistence agriculture for their subsistence, with 97% being rain-fed (Kenga et al.2005)

Due to the overdependence on rain-fed agriculture, sensitivity analysis of climate in the region is characterized by uncertainties; erratic weather patterns such as heat stress, droughts, longer or prolonged dry seasons, and uncertainty in rainfall place additional pressure on already stressed systems. Further changes in the climate variables have drastic consequences on the productivity of the subsistence rain-fed crops as decline in yield due to unfavorable climate will lead to vulnerability in the form of food security and hunger. The agrarian rural poor population rapidly growing at the rate of 2.6 % is at the receiving end of the climatic variability and change impacts leading to pauperization and concomitantly impeding the achievement of the Millennium Development Goals that Cameroon is subscribed to.

The scientific knowledge on impacts of climate change is increasing all the time, as are practical experiences in responding to adaptation needs. This knowledge gap needs to be exploited. With issues on climate change marginally entering into the development agenda in Cameroon and societal resilience thus far not improving, most research on this issue in Cameroon have been based on commercial cash crops (Tingem et al.2008). How subsistence farming communities respond and adapt to these changes particularly in the Sudano-Sahelian zone have been relegated to the backyard. Millet and Sorghum used in this study are the most widely cultivated food crops and serve as a delicacy for the 6.5 million inhabitants that depend on rain-fed agriculture for their livelihood (Kenga et al.2005).

The process of adaptation is not new but the idea of incorporating the present and future climate risk into policy-making is. Local subsistence farmers have developed intricate systems of gathering, predicting and decision making to weather with respect to their agricultural practices.

The local farmers' possess indigenous knowledge in coping with climatic changes and serves as a sink that could be relevant for community based adaptation response options for recent climatic variability and change. This study envisages that tendency as a breakthrough that could act as a springboard in the building of adaptation strategies to climate change that could facilely integrated into local governments' policies and programs in aiding subsistence farmers.

1.6 Conceptual framework of the study

This study employs the top-down and the bottom-up approach of the Third Assessment Report (TAR) of the United Nation Framework Convention on Climate Change (UNFCCC) in the assessment of the sensitivity and vulnerability of crop production systems (UNFCCC 2006) for subsistence farming communities in the Sudano-Sahel of Cameroon. This multidisciplinary approach integrates "bottom-up" knowledge of existing vulnerabilities with "top-down" climatic projections as transparent bases for informing decisions to reduce vulnerability that would concomitantly improve on the adaptive capacities of subsistence farmers.

In order to implement this integrated approach, it requires assessment of historical and current exposure as well as the sensitivity to wide range of climatic and non-climatic conditions. It assesses existing adaptive capacities of subsistence farming communities and decision making processes. The approach makes a blend between biophysical (top-down) and social (bottom-up) vulnerability assessment (Figure 1). By integrating approaches from different paradigms, the proposed process offers a holistic approach for assessing subsistence farmers' vulnerability and concomitantly the development of adaptation strategies

The bottom-up approach utilizes a participatory tool to define and describe subsistence farmers systems and current adaptation to climatic variability and change practices. The Soft Systems Analysis after Checkland (1999) has been applied in establishing the current problem situation with the stakeholders being the subsistence farmers. Key informant interviews were done in the pretext of suggesting other relevant stakeholders' involvement. There was also the administering of structured quantitative structured questionnaires (Annex 1).These questionnaires were aimed at understanding the scale of the problems, processes and transformations occurring within in the subsistence farmers' community set-up. They garnered the perception of subsistence farmers on climatic change and aimed at exploring and conceptualizing approaches by subsistent farmers to adaptive and mitigative capacity and their perceived utility in decision making. These provide a long term view of how environmental changes or socio-economic shocks affect vulnerability context or ways in which communities are vulnerable to external shocks and how they adapt to them. The bottom up gets in-depth into needed capacity and constraints, and access to coping mechanisms of those impacted in responding to changing climatic conditions and the influences of non-climatic stressors interacting with climate change. Also taken into account are the mitigative responses (precautionary principles) targeted towards the driving forces of climate change.

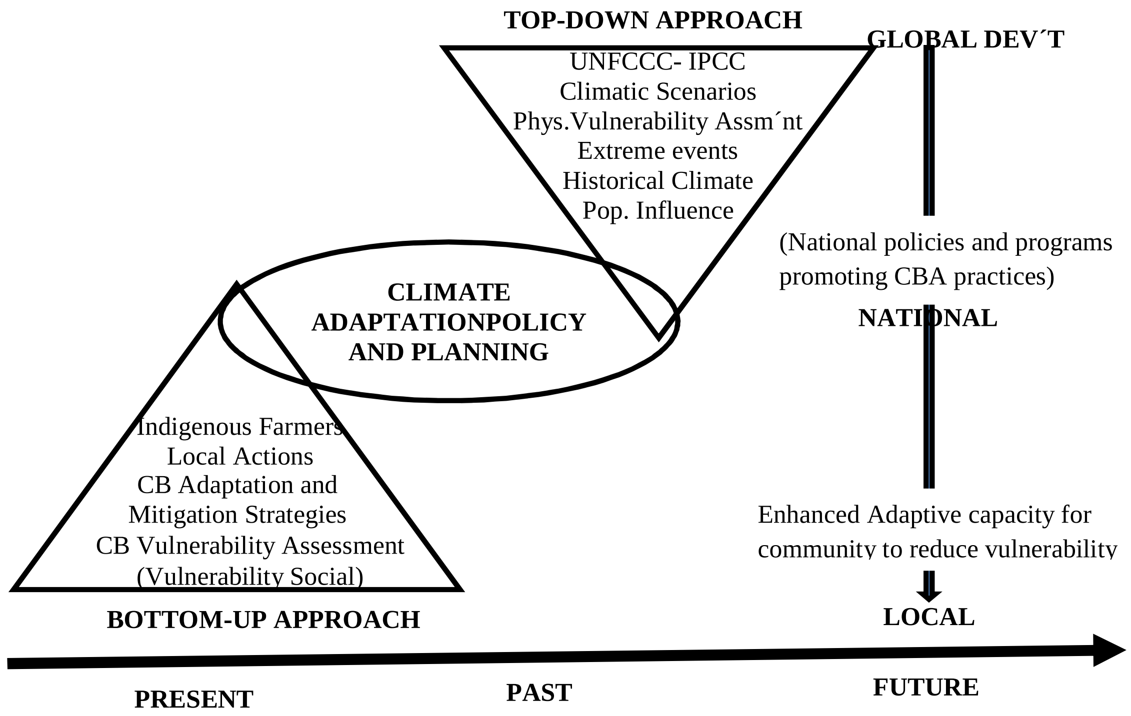


Figure 1. Two complementary approaches to impacts and vulnerability assessment used to inform climate change adaptation policy and planning. Source: Modified from Dessai and Hulme (2004)

Considered a milestone is the application of the Pressure-State-Response (PSR) indicator conceptual framework in incorporating the cause effect relationships in both paradigms. This framework is based upon the idea that human activities exert pressure on the environment that result in changes in the state of the environment as a whole, as well as its individual parts. These changes often cause a societal response, which results in changing environmental policies or implementing management actions (OECD 1994). By so doing, the pressure indicators exerted on the subsistence farmers' environment, state indicators of subsistence farmers crop productivity, and the societal responses to the climatic change extremes were all identified.

From the top-down perspective; with subsistence farmers' overdependence on rain-fed agriculture in the Sudano-Sahel, drought and the population growth factor have both been taken as the pressure indicators on agricultural crop production systems. The Standardized Precipitation Index (SPI) by (McKee et al. 1993) was used in the quantification of agricultural droughts occurrence, and the frequencies and intensities. A detailed description of this has been covered in chapter 5. Spatio-temporal land use and land cover dynamics using remote sensing techniques via Landsat images were applied (Campbell 2002). These were aimed at the identification of the land use and land cover dynamics as a result of human and natural influences on the agricultural system for the three different areas of the Sudano-Sahel study region.

Crop yields and crop harvested areas were identified as the state indictors. Multiple regression models were developed using time series yield anomalies as the predictand and anomalies in minimum temperature, maximum temperature and rainfall for the crop growing season from May –August acting as the predictor variables. The Pearson Product Moment Correlation Coefficient was also used in exploring individual climatic variables relationships with yields for the entire growing period in order to identify those variables that influenced a significant portion of the observed yield variance.

The response indicators were the subsistence farmers themselves and were investigated using the participatory research approach in investigating the sensitivity and vulnerability of subsistence farmers, exploring the adaptation behaviors and patterns they perceived in the face of variable climatic conditions. Figure 2 is the diagrammatic representations, showing the linkages between Pressure State Response (PSR) approaches whereby three simple questions were being put forward pertaining to the impacts assessment of climatic change on subsistence crops, mitigation and adaption options in agricultural crop productivity in the study area: What's happening in the subsistence agricultural environment? Why is it happening? What are we doing about it? (Hammondet al.1995)

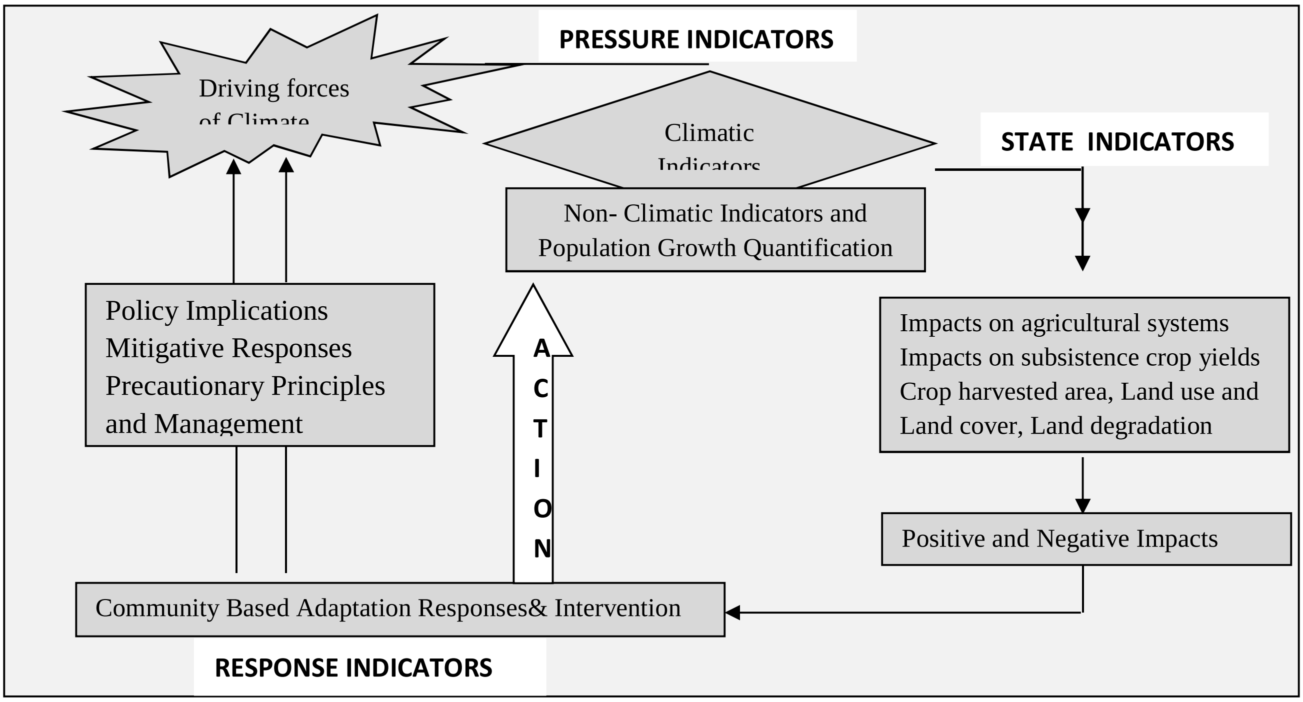


Figure 2. Methodological and the implementation framework of research

1.7 Expected contribution of research

Generally climate change issues have historically focused on vulnerability and mitigation rather than on adaptation and the resilience, particularly of subsistence agriculture. The importance of this study within the framework of community based adaptation cannot be overemphasized. This represents a practical integration of two different paradigms, the top-down and bottom-up approach in impact and vulnerability assessment of the climate-stricken rural farmers of the Sudano-Sahel. The study will be particularly beneficial in the area of knowledge acquisition and capacity enhancement. Scientific publications that will arise will be directed to the academic research communities for public awareness creation on the role of indigenous knowledge in climate change adaptation of subsistence farmers.

With the impacts of climate change already being felt all around the globe, it is the obligation of government agencies, private institutions, non-governmental organizations (NGOs), community based organizations (CBO), in mapping out strategies in tackling these adverse impacts particularly at the local levels where communities have hit hardest. This can only be possible with facts from research! Therefore the findings of this research are envisaged to equip policy makers with needed, relevant and most recent information for appropriate legislations regarding subsistence rural rain-fed agricultural adaptation to climate change. These will bring about increased outputs of farmers and concomitantly enhanced income and minimized poverty.

1.8 Thesis structure

This thesis is structured into 7 main chapters. Chapter 1 commences with the background of the research, the research questions, hypotheses and objectives. The thesis rationale is explained followed by a succinct conceptual framework of the research as well as a diagrammatic methodological implementation (Figure 3). The study area descriptions and characteristics are described in Chapter 2, followed by an overview of climate change, the African climate supplemented with as major climate types in Cameroon. The state of art of Cameroon´s agriculture in the context of climate change is examined, closely followed by biophysical and socio economic determinant of crop productivity.

Literature on climate change adaptation and mitigation are explored in chapter 4. Details of primary and secondary data acquisition are described in the methodology embedded in chapter 5. Both the top-down and bottom-up approaches are thoroughly discussed. Statistical formation related to the climate, subsistence crop productivity and the demographics in the Sudano-Sahel are presented with explanations of the methods used in testing the hypotheses. The results are then presented, closely followed by the discussions of the findings encompassed in chapter 6. Chapter 7 synthesizes the research findings in policy implications, with some conclusions and recommendations made. Outlook for further research on subsistence agricultural adaptation to climatic change are then outlined.

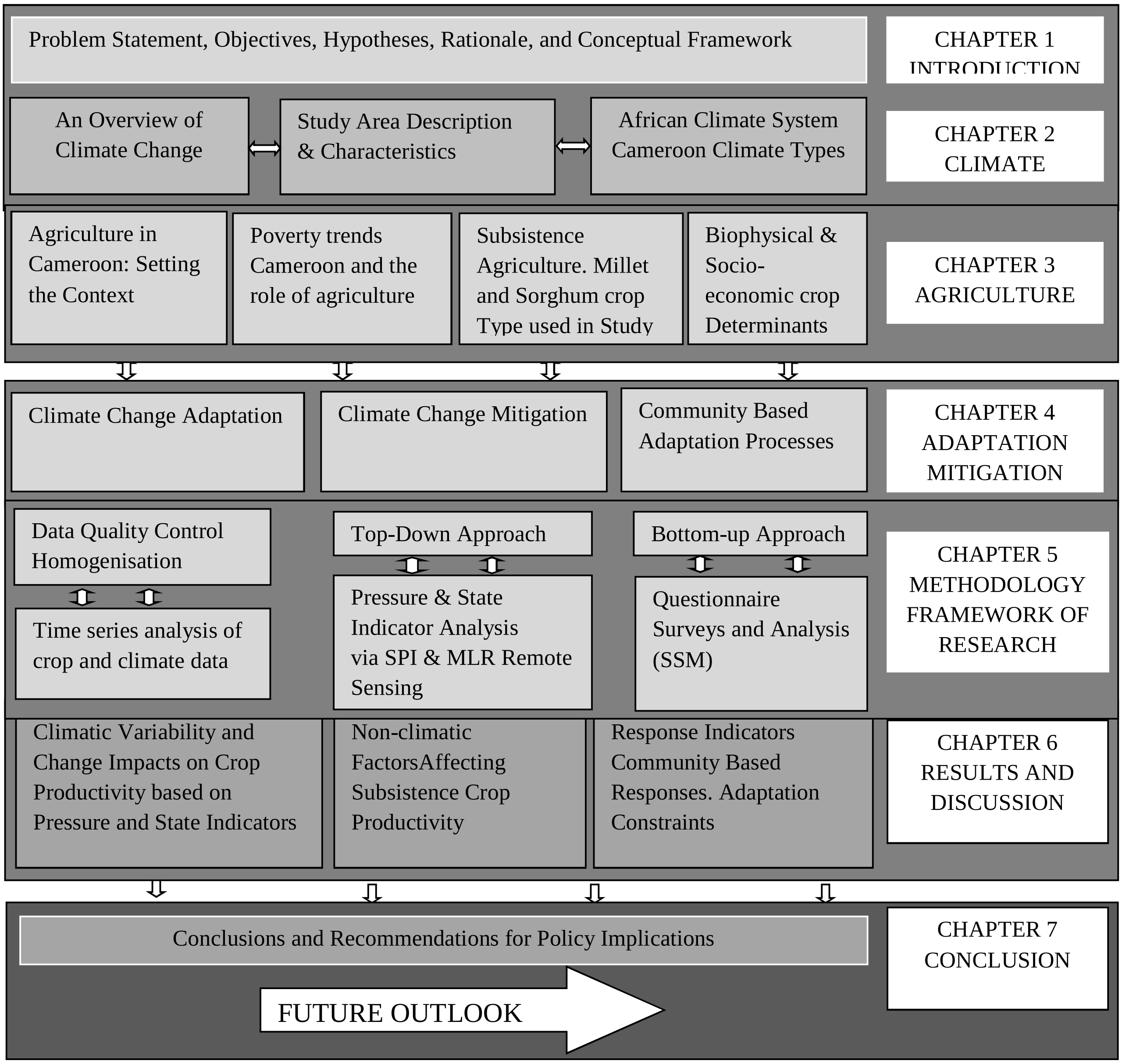


Figure 3. Structure of thesis

2. An overview of climate change

For a deeper understanding of climate change, it is essential to distinguish between weather and climate as they are mutually exclusive events that affect in a complex way human presence and activities on the earth. Weather is the state of the atmosphere above a given place at a specific time. It is the day-to-day state of the atmosphere in terms of air temperature and moisture, cloud covering, relative humidity. Weather is derived from the chaotic nature of the atmosphere and is unstable as it is affected by perturbations.

Climate on the other hand is described as average weather over a defined time period. Weather is a scientific concept. It deals with statistics such as the average of all-weather events, or over a long period of time (normally 30 years). Weather has a very limited predictability effect and could be directly perceived by people while climate cannot (Kropp and Scholze 2009). Or a popular phrase puts it: climate is what you expect and weather is what you get. Climate varies from place to place, depending on latitude, distance to the sea vegetation, presence or absence of mountains or other geographic factors. Climate also varies in time, from season to season, year to year, decade to decade or on much longer scales such as the ice ages. The statistical significant variations of the mean state of the climate or of its variability, typically persisting for decades or longer have been referred to as “climate change” (Baede et al. 2001)

2.1 The earth´s climate system

The complete earth climate system can be considered to be a five-part system (IPCC 2001) consisting of: (1) the atmosphere, which is composed mainly of nitrogen (N_2, 78.1% volume mixing ratio), oxygen (O_2, 20.9% volume mixing ratio) and argon (Ar, 0.93% volume mixing ratio), (2) the hydrosphere, which is the component comprising all surface and subterranean water in liquid phase, both fresh and saline, (3) the cryosphere, consisting of every form of ice: glaciers, snow fields, sea ice and permafrost, (4) land surface and (5) biosphere, both marine and terrestrial. The physics underlying the climate system is well known and widely understood and is determined by many factors, processes and interaction at global scale and are have been illustrated in figure 4. These components interact with one another and with aspects of the earth's biosphere to determine not only the day-to-day weather, but also the long-term averages that we refer to as 'climate'.

The climate system is driven by energy received from the sun (sunlight). Some of this energy is reflected back into space, but the rest is absorbed by the land and ocean and re-emitted as radiant heat. Some of this radiant heat is absorbed and re-emitted by the lower atmosphere in a process known as the greenhouse effect. The earth's average temperature is determined by the overall balance between the amount of incoming energy from the sun and the amount of radiant heat that makes it through the atmosphere and is emitted to space.

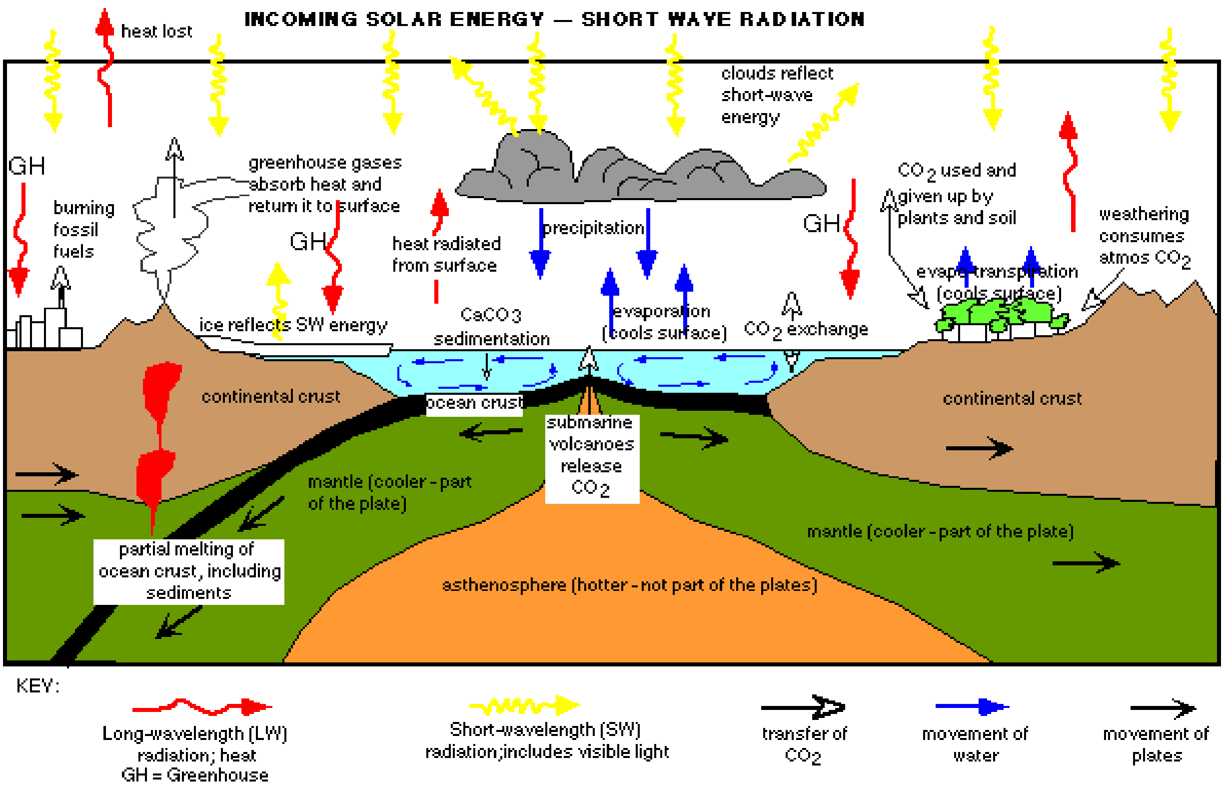


Figure 4. Schematic view of the global climate system. Source: (HAGTW 2010)

A crucial feature of the climate system is that the sun's energy is not distributed uniformly, but rather is most intense at the equator and weakest at the poles. This non-uniform energy distribution leads to temperature differences, which the atmosphere and ocean act to reduce by transporting heat from the warm tropics to the cold Polar Regions. This non-uniform heating and the resulting heat transport give rise to ocean currents, atmospheric circulation, evaporation and precipitation that we ultimately experience as weather (Wang et al.2004).

2.2 The African climate system

Africa's climate is naturally very diverse and highly variable. It encompasses the extreme aridity of the Saharan deserts at one end of the range and the extreme humidity of the Congo rainforest at the other. Interacting with these natural patterns are the combined effects of anthropogenic global warming and human interference more generally. In most instances it is difficult or impossible to disentangle one cause of change from another. For example, the countries of the Sahel have experienced many multi-decadal periods of drought since end of the last glaciations 12,000 years ago (Collier 2008).

The African climate is in itself determined at the macro-level by three major processes or drivers: tropical convection, the alternation of the monsoons, and the el niño-southern oscillation of the Pacific Ocean. The first two are local processes that determine the regional and seasonal patterns of temperature and rainfall. The last is more remote in its origin, but strongly influences the year to year rainfall and temperature patterns in Africa (Conway 2009).

Adding to tropical deforestation, pasture land degradation and biomass burning of the savannahs contribute to the anthropogenic greenhouse gases effects. The climate in Africa is also a driver at a global level. The Inter-tropical Convergence Zone (ITCZ) releases enormous heat. It is the major source of the planet's atmospheric warming. Africa is also a source of the Atlantic hurricanes that often develop from easterly atmospheric waves passing over Africa at the time of the monsoon (Conway 2009).

Wind-borne dust also produces large quantities of aerosols. The effects of aerosols on climate are highly complex. In certain circumstances, some aerosols reflect incoming radiation, thereby cooling the planet, but others trap the heat and add to the greenhouse effect. Dust can either reduce or stimulate rainfall. In low clouds, water attaches to dust particles and prevents droplets from becoming heavy enough to fall. But in high clouds dust particles over wetter regions may provide surfaces for ice crystals to form around them, resulting in greater rainfall. (Nicholson 1994; Brooks 1999) A typical example are the great Saharan dust storms that are by far the largest source of dusts on the planet and are blown in long distances, influencing weather on the far side of the Atlantic.

2.3 Major climate types in Cameroon

Cameroon most often is described using various names such as the “melting pot of Africa” or “Africa in miniature” or better still “Africa in microcosm”. Consequently, it has a wide range of climatic types from the wet southern region near the equator to the dry north extending towards the Lake Chad basin. Going westward stands the Mount Fako that extends its slopes into the Atlantic Ocean. There are two broad climatic categories: The equatorial climatic zone and the tropical climatic zone and are subdivided into different types as described in the following lines.

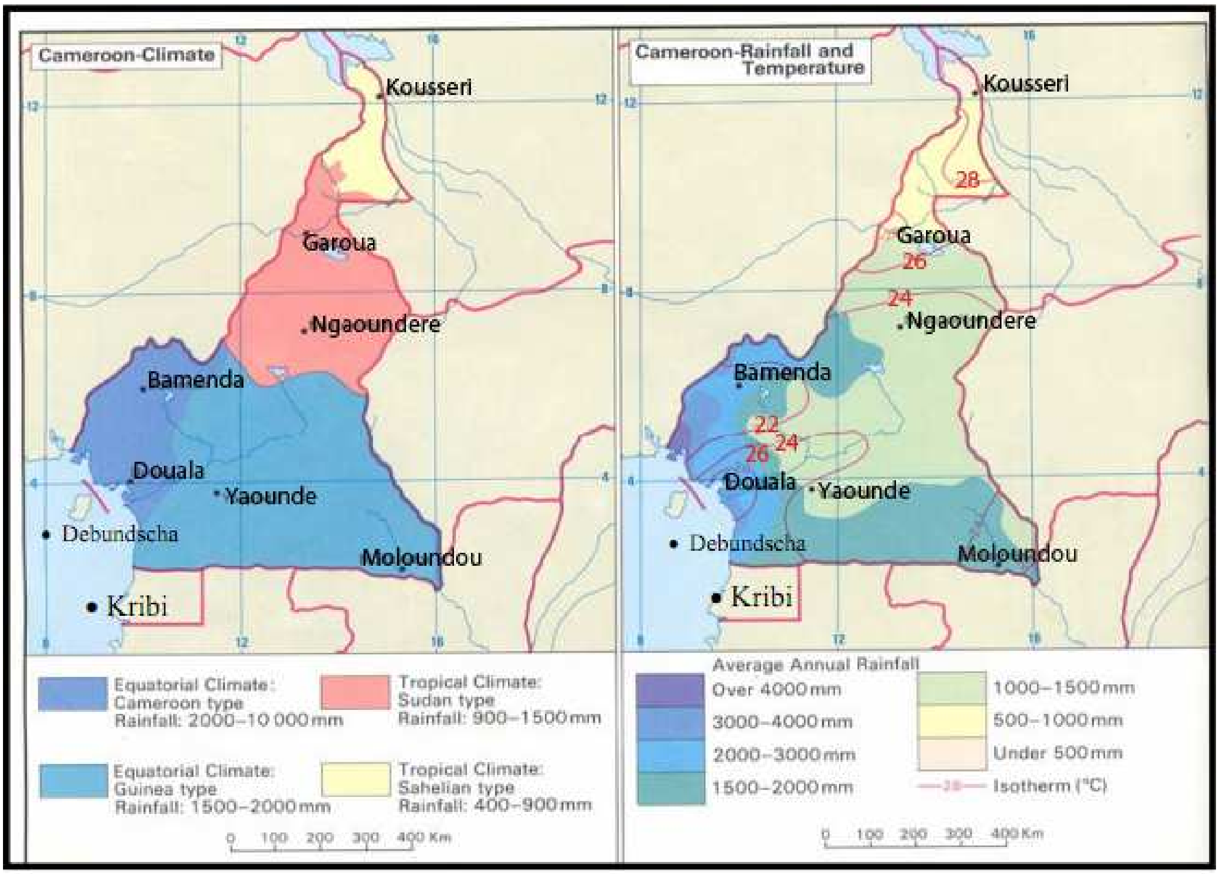


Figure 5. Cameroon of climate: Rainfall and Temperature regimes (Source: modified from Fomensky et al.1985).

2.3.1 The Equatorial climate domain

The southern part of the country that extends from latitude 2 degrees to 6 degrees North is characterized by an Equatorial climate which is further subdivided into two categories:

2.3.1.1 The Guinean type:

Covering nearly one-third of Cameroon, this climatic type is found in the southern part of the country, with much extending from the coast at Kribi and covering the southern Plateau. It is marked by four seasons per year; two rainy and two dry seasons. Rainfall is abundant and ranges between 1500 to 2000mm. Temperatures are high and fairly constant measuring about 25 degrees Celsius on the average.

2.3.1.2 The Cameroon type:

Climate which occurs on the south-western coast near Mt. Cameroon and extends down the mouth of the Sanaga River and the Western and Bamenda highlands, is hot and humid with a wet season of about eight months during which rains are abundant throughout, and a comparatively short dry season. Pamo et al. (2008) further divides this type into the two: - The maritime Cameroon type: The mountain Cameroon type:

The maritime Cameroon type:
Extends from the coastal region right up to the mouth of the River Nyong .This section encompasses the second rainiest part of the world, Debundscha, having rainfalls averages of 10,000mm per year. Humidity here is high and the influence of the mount Fako is ever present

The mountain Cameroon type:
This prevails on the Western Highlands including places like Buea, Dschang, Bamenda, Kumbo etc. It extends northwards until it meets with the next climatic region, the tropical Sudan type.

2.4.2 The Tropical climate domain

This is subdivided into the Humid Tropical and Sahel Climate.

2.4.2.1 The Humid tropical climate type

The Humid tropical climate type extends from about latitude 6 to 10 degrees. Rainfall here is about 1500 mm and there are two distinct seasons; the rainy and the dry season. The rainy season lasts for over seven months meanwhile the dry season lasts for between 3 to 4 months in some cases. The average temperatures here measures about 21 degree Celsius.

2.4.2.2 The Sahel type

The Sahel type which starts from the north of the Benue basin and covers the plains of Mayo-Danay, the Diamare and the Mandara Mountain, is characterized by low precipitation, usually below 900 mm and a dry season of at least seven months. Low atmospheric humidity increases annual temperature ranges (7°C) and the level of dryness. The Mandara Mountains differ from the rest of the area due to altitude which results in cooler, more humid conditions (Mokolo 967 mm) though the dry season is still long. On the Chad Plain arid conditions are intense (Kousseri 630 mm) and the rainy season barely lasts three months with a very high rate of evaporation (Mphoweh and Futonge 2009).

2.5 Seasonal types

Two distinct seasons exist in Cameroon and they come about as a result of air masses. The movement of two major air masses across the country account for the two main seasons. These winds are referred to as the trade winds. They originate in the Northern hemisphere from the Azores anticyclone and in the south from the St. Helena anticyclone. The two air masses often converge over a low pressure center called the Inter Tropical Convergence Zone (ITCZ) forming a front called the Inter-tropical front. The movement of this front depending on the dominant trade wind at the time conditions the type of season (Pamo et al. 2008). For example when the south trade winds (also called the monsoon) blow more from the ocean pushing this front inland, this leads to the rainy season and conversely when the trades from the north also called the Harmattan push this front more down south, it leads to a general dry season.

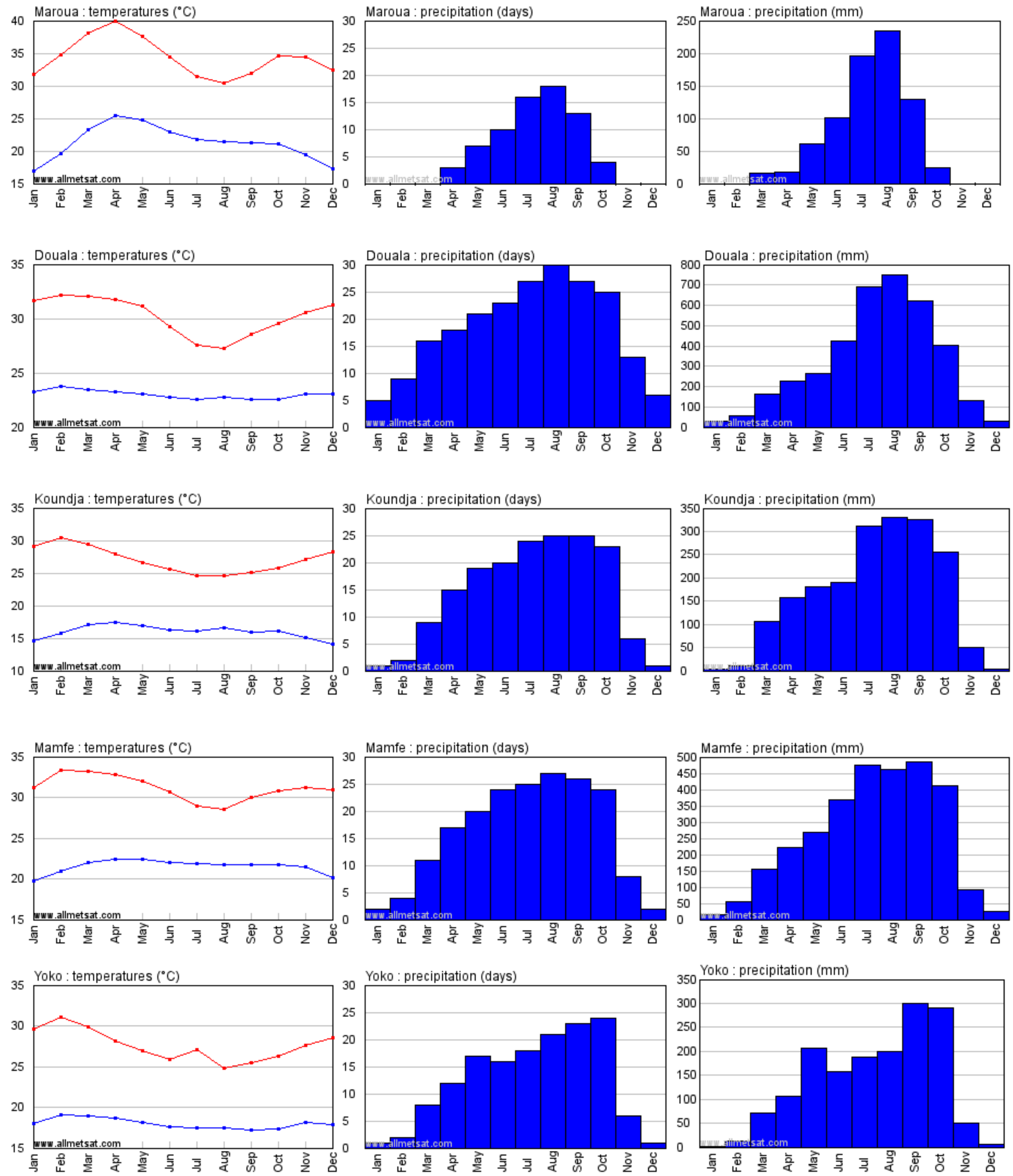


Figure 6. Climatic histograms for some selected weather stations in Cameroon showing monthly averages of the minimum and maximum daily temperatures in °C, the number of days with precipitation ≥ 1 mm, and the average monthly precipitation (Source: modified by author from WCD 2013).

The advent of the dry season in most parts of the country is often manifested by a total stop in the rainfall, harsh sun, blue skies and a generally dusty atmosphere. It also marks the end of several fluvial regimes. The arrival of the rainy season on the contrary is like the advent of new hope especially for farmers who get back into total activity.

2.5.1 Rainfall regimes

This is a phenomenon that is influenced by proximity to the sea and also the south to north extension of the country. Same too as temperature, it is also influenced by altitude. It is therefore for this reason that spatial variations exist throughout the country. For instance, Douala receives 4,016 mm of rainfall annually, Yaounde 1,596mm, Lomie 1,654mm, Bamenda, 2,596mm, Garoua 1000mm and Kousseri in the Far North region receives only 630mm. Relative humidity varies in the same manner as rainfall based on the proximity to the coast.

Symptomatic of these combination of factors is the occurrence of four distinct seasons in the south and central parts of Cameroon; these include: the long dry season at the beginning of the year, the long wet season from September to December, a short dry season in August and a short wet season between March and June. From the Adamawa to the Lake Chad which marks the Northern section of the country, there are two distinct seasons: a long dry season from November to April and a short wet season from May to October (see figure 6). The average rainfall is shown on the graph below as well as a histogram for some stations in Cameroon and their average rainfall and temperature.

2.5.2 Temperatures

Cameroon falls within the inter-tropical zone and experiences yearly temperatures varying between 20 to 28 degrees Celsius. Temperatures generally increase from the south towards the north; this explains why there is a change from a humid and ever green south towards a hot and desert North. The temperature is also influenced by the proximity to the sea; the more you go hinterland, the hotter it becomes. Both situations are however waved off in several cases by altitude which influences the temperature; the higher you go, the colder it becomes as is the case with Yaoundé which is higher (23.5 degree Celsius) and Garoua (28 degree Celsius) which in within the Benue Plain. Average rainfall in Cameroon is shown in histogram on Figure 6.Time series created for the study area of Maroua, Garoua and Ngaoundere are shown in the figures 7-12 with the average monthly rainfall and the potential evapotranspiration (PET)

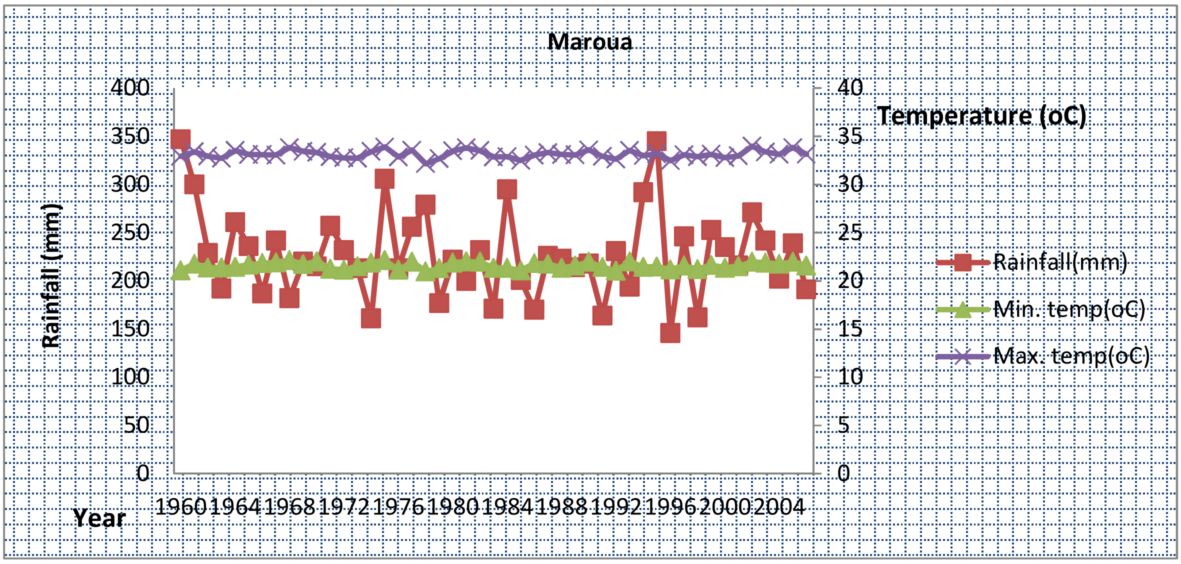


Figure 7. Maroua Time series annual rainfall, minimum and maximum temperature (1961-2006)

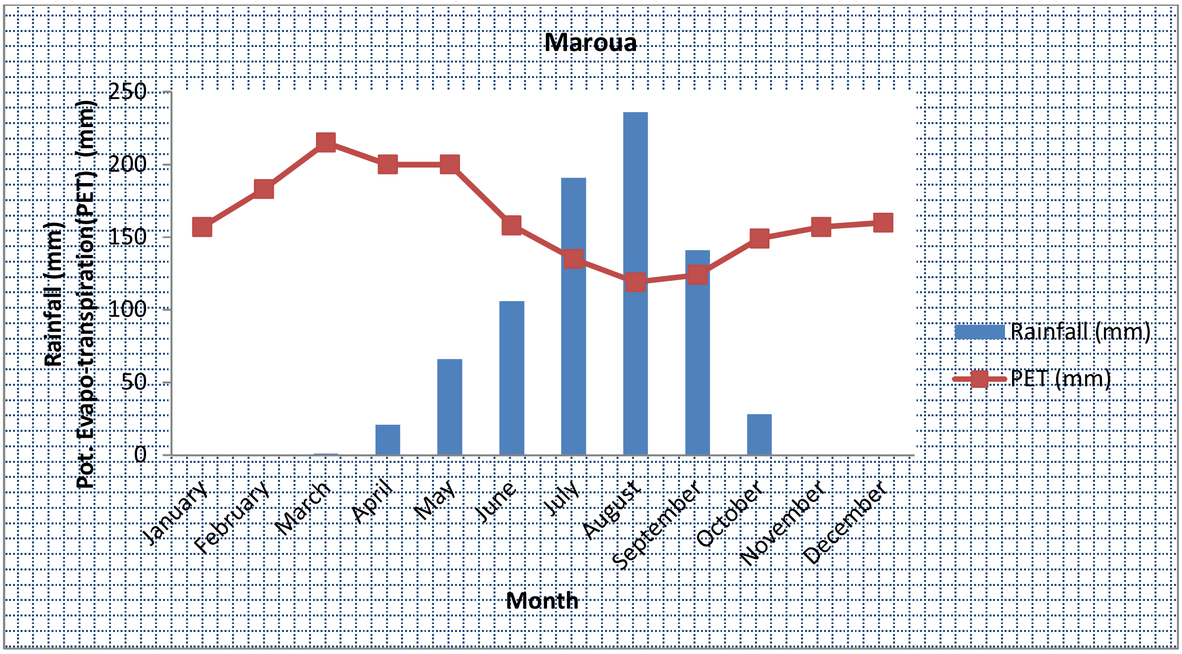


Figure 8. Average month precipitation and the potential evapotranspiration for Maroua

Data Source for PET: (compiled from Sanders de Haas 2010)

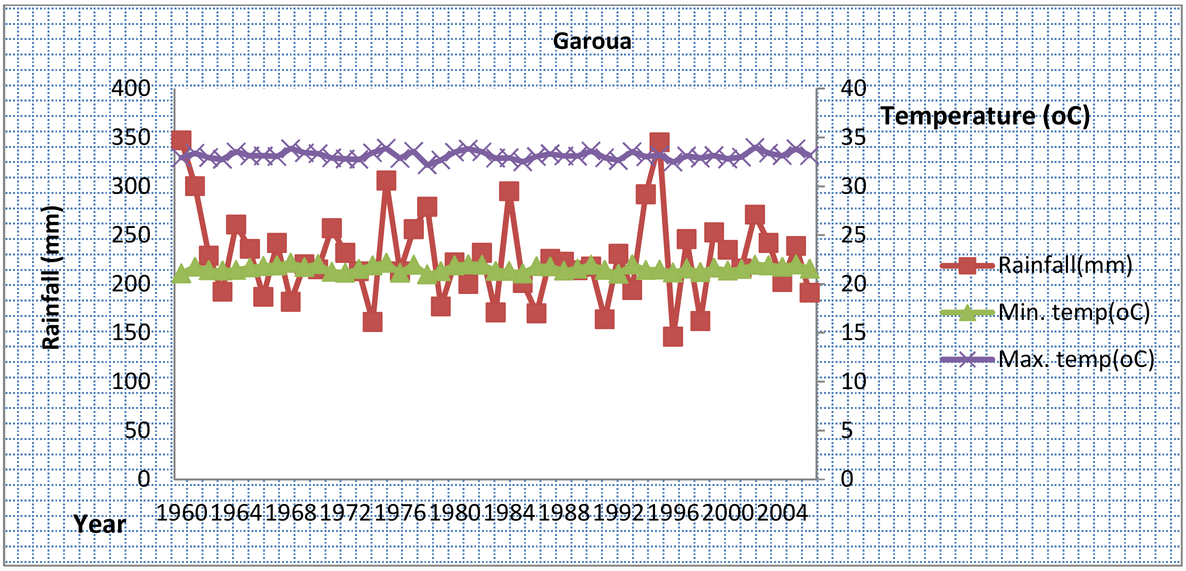


Figure 9. Garoua Time series annual rainfall, minimum and maximum temperature (1961-2006)

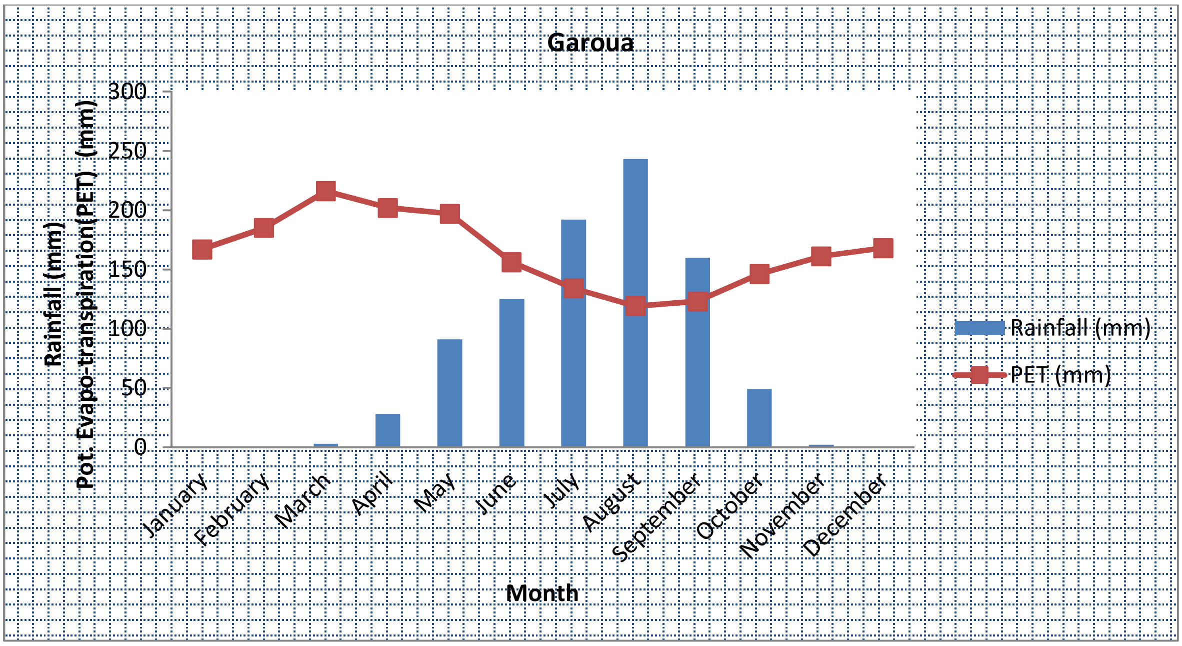


Figure 10. Average month precipitation and the potential evapotranspiration for Garoua

Data Source for PET: (Sanders de Haas 2010)

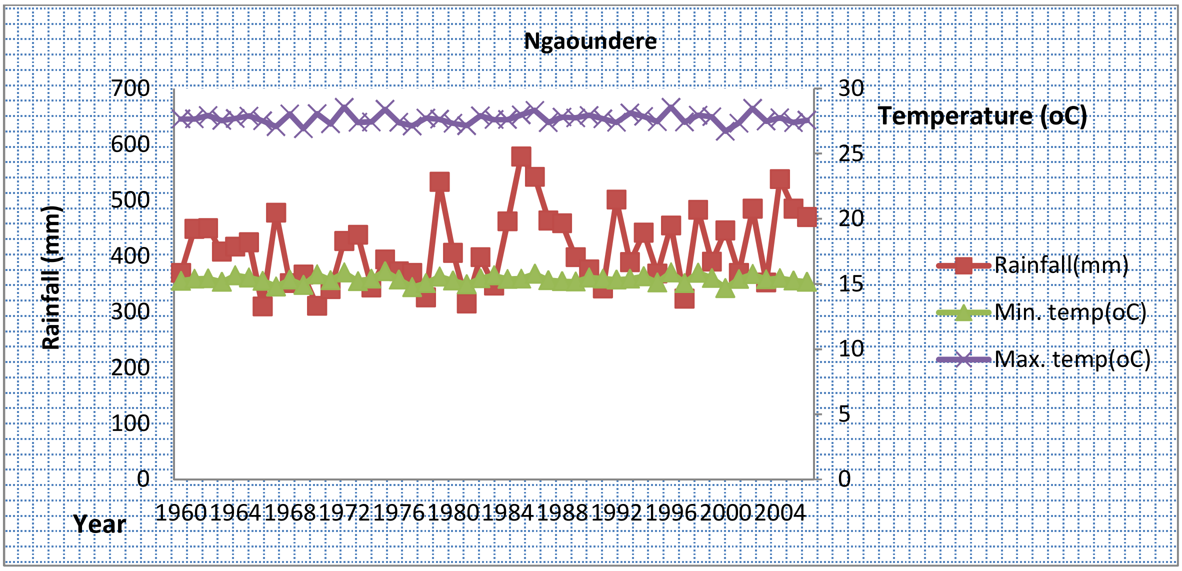


Figure 11. Ngaoundere Time series annual rainfall, minimum and maximum temperature (1961-2006)

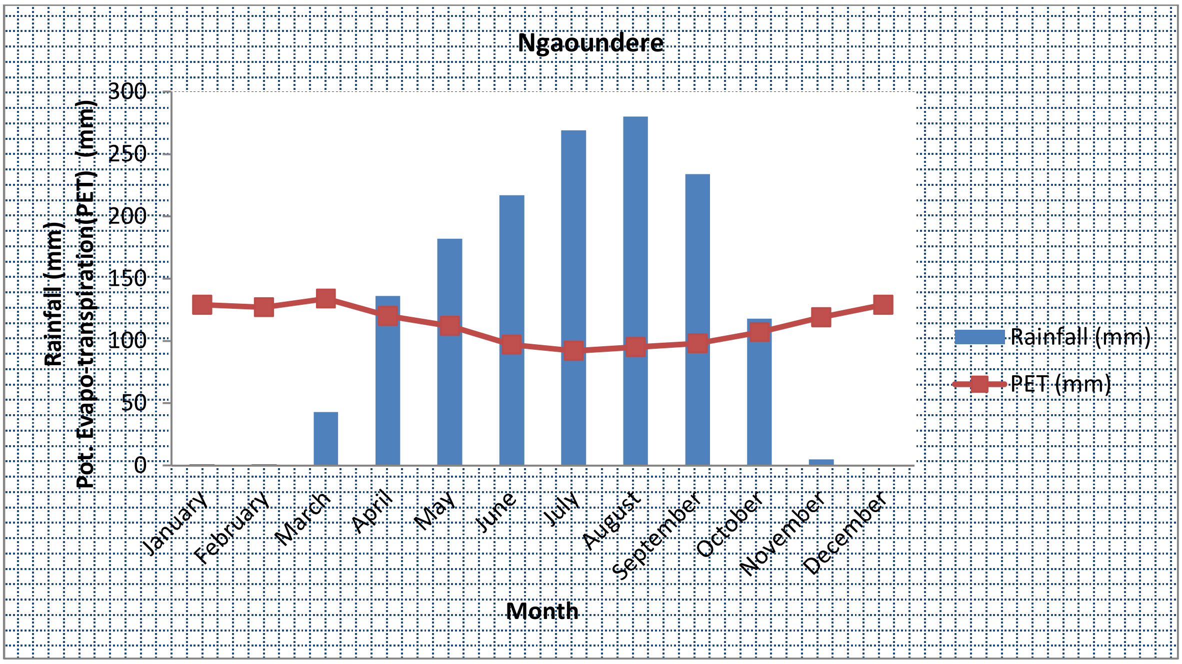


Figure 12. Average month precipitation and the potential evapotranspiration for Ngaoundere (Data source for PET: Sanders de Haas 2010)

2.6 Study area

2.6.1 Description and climate

The Sudano-Sahel is a vast area just south of the Sahara. Cameroon´s Sudano-Sahelian zone extends between Latitude 7° 30´ to 13° North and Longitude 9 ° to 15 ° East (figure 9) (Kenga et al.2005). The climate of the zone is Savannah, with alternating wet and dry seasons. In the Koeppen Classification, it is described as Climate Type AW/BS, characterized by tropical humid with dry winter and semi-arid (Koeppen 1936). Rainfall distribution is monomodal or unimodol (Yengoha 2011); and the region experiences a long dry season. Rainfall in this zone is highly variable with its onset very erratic and last for about 5 months (May-September). Erratic patterns are usually observed in the months of April and October. There exist intra-annual differences in the amount of rainfall received by the Sudano-Sahelian. The southern part receives more rain and is less variable compared to the northern section. Rainfall patterns in the region as in other parts of Cameroon as a whole are usually attributed with what is often called the Inter Tropical Discontinuity and receiving a total of 300-800 mm of rain per year. The average growing season length varies from 60-150days, with larger parts having growing seasons of less than 120days (SiIvakumar 1989). The efficient use of the limited rain is crucial due to the dependency of the population on rain-fed agriculture.

Table 1. Agricultural land area distribution in the Sudano-Sahel study area

Regions	Total Areas		Agricultural lands				
	Km^2	in % of total	Potential in Km^2	Potential in %	% of the region	Cultivated in Km^2	Cultivated in percentage of potential
Maroua	34 260	7.4	6 722	9.9	19.6	4 117	61.2
Garoua	67 808	14.6	17 032	25	25.1	1 500	8.8
Ngaoundere	61 992	13.3	13 319	19.6	21.5	830	6.2

(Source: MINEF 1996)

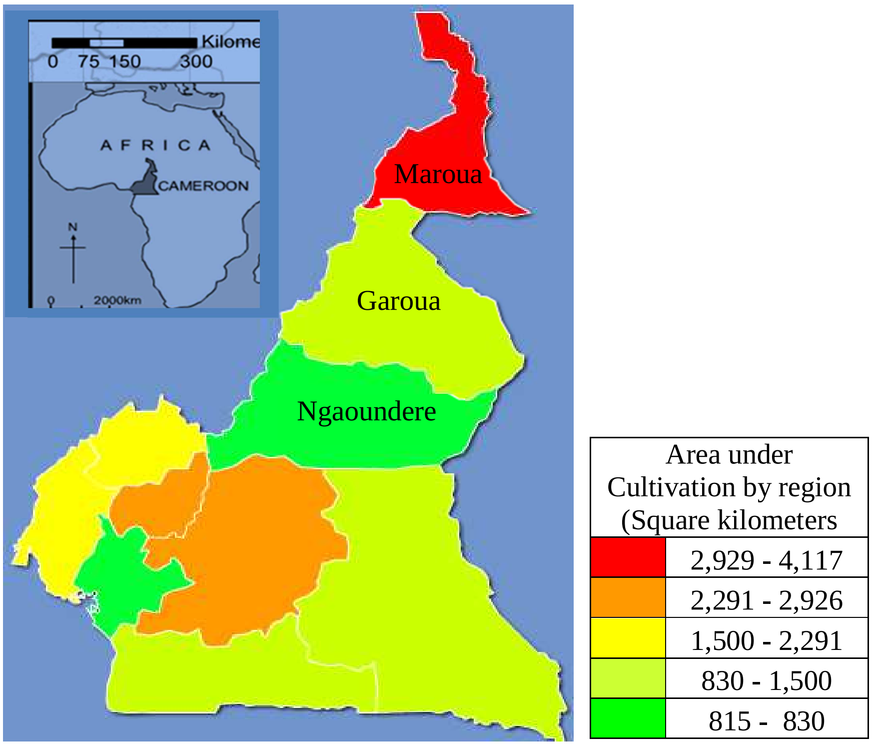


Figure 13. Agricultural land use map of Cameroon, showing the Sudano-Sahel study areas of Maroua, Garoua, and Ngaoundere with the respective area under cultivation (Source: Modified from Eyembe 2012)

2.6.2 Population trends and patterns

The Sudano-Sahel population is estimated at about 6.5 million in habitants with 67 percent constituting the rural population (Ministry of Economy, Planning and Regional Development 2010). Average demographic growth rate is at 2.6 percent and 70 percent of the population depending on agriculture for their livelihood. From the political point of view, this zone constitutes three regions. The Far North, North and the Adamawa regions with their capitals being Maroua, Garoua and Ngaoundere respectively.The population growth and density of the Far North Region of Cameroon (1976-2010) have been shown on the table 2. The numbers between 1995-2000 are estimated based from the studies published by of Moritz in 2010. 2010 numbers are from the latest press release of the Ministry of the Economy, Planning and Regional Development 2010.

Table 2. Population growth and density of the Far North Region of Cameroon (1976-2010)

Region / Year	1976	1987	1992	1995	2000	2005	2010
Population of the Far North Region	1.396.124	1.880.866	2.141.100	2.467.000	2.838.000	3.200.000	3.480.414
Density per Km^2	40.8	54.9	62.5	72.0	78.8	82.0	89.0
Population of Maroua	62.600	123.000	162.000	190.000	243.500	280.000	344.000

(Source: Moritz 2010)

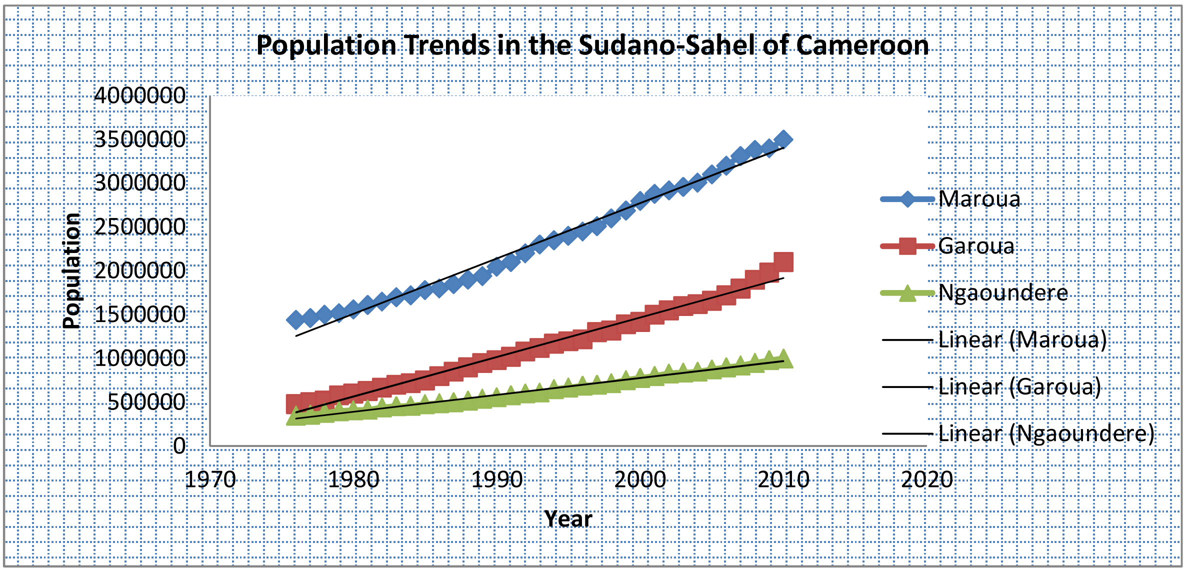


Figure 14. Population trends for Maroua, Garoua and Ngaoundere study region

2.6.3 Soil characteristics

Over time, various soil formation processes have given rise to important pedological heterogeneity in the Sudano-Sahel. Based on the FAO soil classification, different major soil types have been distinguished. These include: - the Vertisols, andosols, the fluvisols, the Planosols and the Lixisols (Kenga et al. 2005). These soils have a characteristics sandy to sandy loam textures, low in organic matter contents and low in native fertility, with limiting nutrients for crop growth (Manu et al.1991) exception of the andosols identified in the Adamawa region that is good for agricultural cultivation. The soils are also structurally unstable and prone to crusting and hardsetting, and have a low water holding capacity (Valetin 1995; Payne et al.1990). Soils of the Garoua region have been identified as fluvisols while vertisols have been extensively identified in the far north region (Maroua).

2.6.4 Vegetation and agricultural farming systems

The vegetation is semi-xerophytic and is transitional between the Sudan Savanna woody grassland to the south and the open desert to the north. In the southern parts where the Sahel merges with the Sudan zone, savanna makes up the vegetation. The vegetation consists mostly of open grassland and thorny woody species. Annual grasslands dominate the northern Sahel, while wooded grasslands occur on sandy soils in the southern part. Among the most important woody plant species are various species of acacia, and baobab. In some locations, the vegetation is concentrated in strips separated by patches of bare soil. Grasses are dominant of plant life with some scrubby bushes with corresponding vegetation varying from steppes to tall grasses and scattered trees (Oyoade 1977).

Diversity is the norm in Sudano-Sahelian farming systems. Subsistence and commercial farming are practiced. Stephenne and Lambin (2001) put forward land-uses that generate basic resource of the population in the Sudano-Sahel. These include: - food for subsistence, fuel wood in the natural vegetation areas, market needs in croplands, fallowing, and livestock in the pastoral land. The agricultural system practiced is characterized by shifting cultivation (slash and burns or swidden agriculture). Crops and livestock are of similar importance and the pressure on arable land is high. Sedentary farming combined free roaming livestock with rain-fed agriculture. The population tends to live on permanent villages although part of their herd may continue to migrate seasonally with herd boys and through entrusted arrangements.

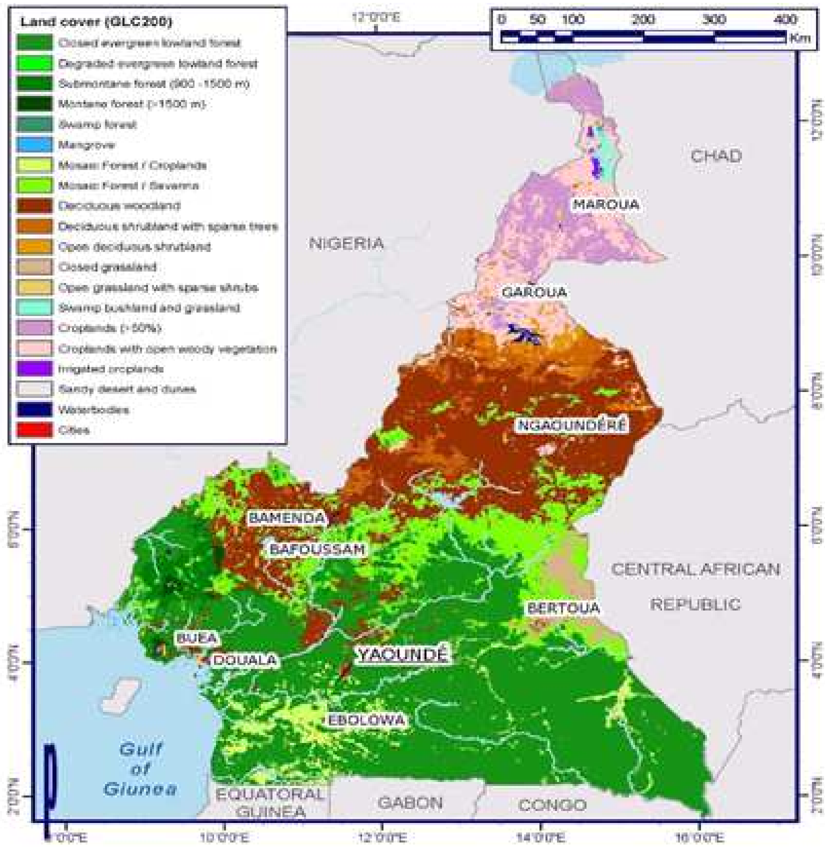


Figure 15.Vegetation map of Cameroon. (Source: Ministry of Forestry and Wildlife and World Resources Institute, Interactive Forestry Atlas of Cameroon, version 2, Yaounde, 2007)

Fallows act as grazing zones for animals. Livestock breeding at times could be classified as farmer-livestock breeding, or transhumant (pastoral nomadism). Crop cultivation is usually done with rudimentary equipment such as hoes and cutlasses.

Cotton based cropping, cereal based cropping and ruminant based livestock activities comprise the land use pattern. The agricultural land falls into 2 discrete categories: rainy season fields and dry season fields. Commercial farming is done by a para-statal –SODECOTON (Societe pour le de Developpement du Coton au Cameroun) that sets up block system in order to standardize plot sizes and facilitate application of animal traction and chemical inputs as well as market organizations.

3.0 Cameroons agriculture

3.1 Setting the context

Cameroon is located in Central Africa, at the Bight of Biafra and precisely between latitudes 2° and 12° North and longitudes 3°and 16° east. It shares boundaries with Chad to the north, Nigeria to the West, Equatorial Guinea, Gabon and Congo to the south and Central Africa Republic to the East (Figure 16). The territory is roughly triangular with a base of about 700 km and a height of 1 200 km; all covering a total land surface area of 475 412 km^2. About 70 thousand km^2 of the total surface area is agricultural land with only 30 % cultivated. (FAO 2003). According to the World Fact book the July 2010 population estimate was 20 million with a growth rate of 2.6 %.

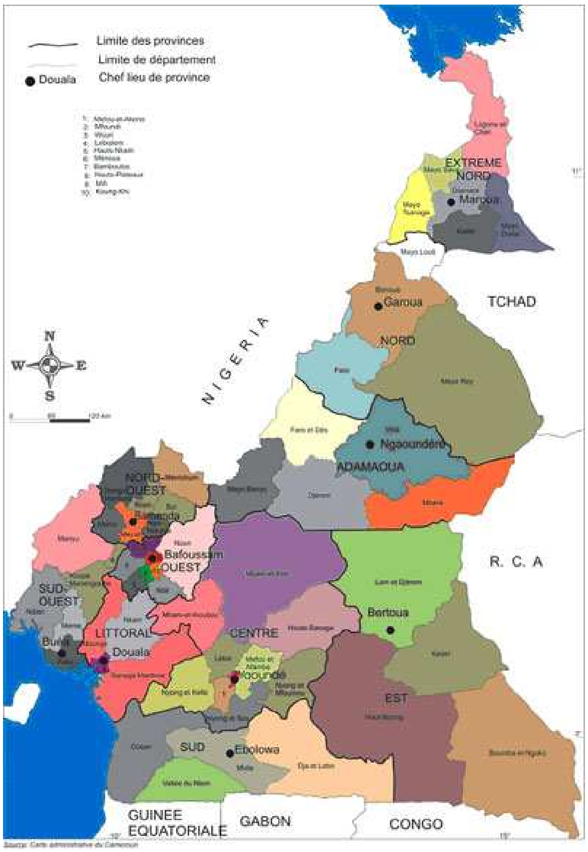


Figure 16. Map of Cameroon showing the different regions and its border countries (Source: Pamo et al. 2008)

3.2 The role of agriculture in the economy

Having a rich and diversified commodity-based economy, agriculture was the sole engine of growth and foreign exchange earnings until the early 1980s when oil became the primary engine of growth. Despite being the fifth biggest oil producer in sub-Saharan Africa, the backbone of Cameroon's economy is agriculture. Out of a total surface area of 475 412 km^2, 68 125 Km^2 are agricultural lands and only 28.9 % are actually cultivated (Pamo 2008). It has a dual agricultural economy comprising of a commercial sector and a predominant subsistence sector consisting of cattle ranching, crop cultivation and mixed farming (figure 21 showing agricultural map of Cameroon). These all play a dominant role in supporting livelihoods and economic growth to the whole region as they provide food, income, power, stability and resilience to rural livelihoods. With agro-processing an important part of Cameroon's industry, agriculture is the livelihood basis for over 70 % of its workforce, while providing 42 percent of its GDP (table 3) and 30 percent of its export revenue (MINEFI 2010).

Table 3. Gross Domestic Product (GDP) real growth rate (%) trends for Cameroon

Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Real Growth rate (%)	5.2	4.4	4.0	5	4.0	3.7	2.3	3.2	3.3	2.9	2.0	3.0	3.8

(Source: African Economic Outlook 2011)

To the economy, the agricultural sector plays an important role through its impact on overall economic growth, households' income generation, and food security. The major cash crops include cocoa, cotton, coffee, palm kernels, tobacco, rubber, banana, sugarcane, and palm oil – grown in the south while cotton and groundnuts are grown in the north. See figure 17 of major cash crops production outputs (tons).

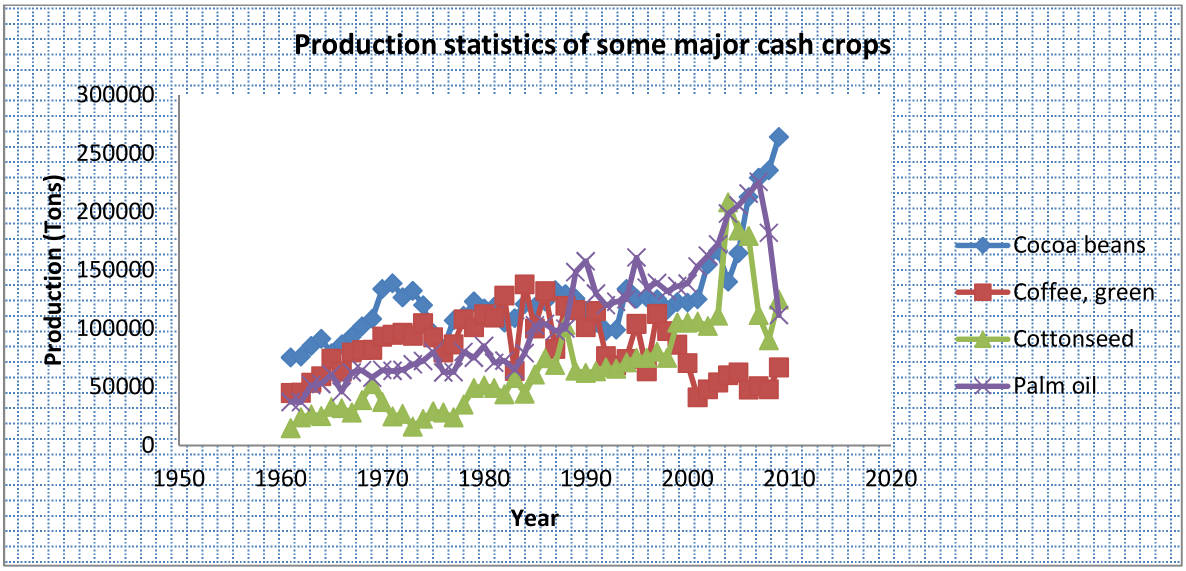


Figure 17. Time series production statistics of some major cash crops 1961-2010 (Source: FAOSTAT 2010)

3.3 Poverty in Cameroon

Poverty in Cameroon in is not only a dominant rural phenomenon, but the country as a whole is worse-off today then before 1986. It affects the rural population much more then urban areas of the economy and its incidence remains high affecting 40.2 percent of the total population (NIS 2007). The poverty line in Cameroon is estimated at 256 francs CFA (approximately 50 dollar cents:- roughly US 1$ per person per day or 19000 FCFA per month) which represents the estimated annual income necessary for an individual in the Capital city of Yaoundé to buy a minimal basket of essential food and non-food items, including health, education and housing expenditure (Amin and Dubois 2001). Based from the reports from Enquete Camerounaise aupres des ménages, ECAM II (2001) on table 4, the analysis of rural poverty shows that it is distributed according to agro-ecological zones with 47.78 percent of the people being poor in the urban areas as against 85.28 percent in the rural areas. Particular attentions should be given to the figures in bold that encompass the Sudano-Sahelian study area.

Table 4. Incidence of poverty by region

Zones	1996	2001	Percentage Change
Urban	41.4	22.1	-19.3
Douala	37.3	18.5	-18.3
Other cities	36.3	26.2	-10.1
Forest	72.5	55.4	-17.1
High Plateaus	62.5	50.7	-12.2
Sudano Sahel Savannah	**44.4**	**45.7**	**1.3**

(Source: Amin and Dubois 2001)

The rates are high in the forest zones and in the high plateaus. In those regions however, there has been noticeable decline in poverty where its incidence was 55.4 percent and 50.7 percent respectively in 2001; compared to 72.5 percent and 62.5 percent in 1996, representing a decline of 17.1 and 12.2 percentage points respectively. On the country, the phenomenon has accentuated in the Sudano-Sahel Savannah zone especially in the North and Extreme region (study area) where the incidence rose by 1.3 percentage points with an estimated 35 percent of the urban population being poor as against 53 percent of the rural population. However, the Littoral and the Center region harbor the least percentage of poor people

Table 5. Poverty index of the different regions in Cameroon

Region	Population (based on 2002 Census)	Poverty index of urban Population (%)	Poverty index of rural Population (%)	Poverty index of total Population (%)
Extreme north	**3.069.888**	**35**	**53**	**49**
North	**1.375.442**	**28**	**49**	**44**
Adamawa	**818.465**	**26**	**43**	**37**
East	854.849	21	33	30
Center	2.729.843	11	21	16
South	617.831	12	20	18
South West	1.375.442	13	24	21
North West	2.045.148	16	29	26
West	2.214.470	14	24	21
Littoral	2.233.321	11	21	13

(Source: MINAGRI/WFP 2001)

With increasing annual population trends in Cameroon, figure 18shows the urban population annual growth rate that has increased by about 3.7% ; the annual growth rate of change of urban population increasing by 1.7 % while the annual rate of change of rural population is -1.88 %.

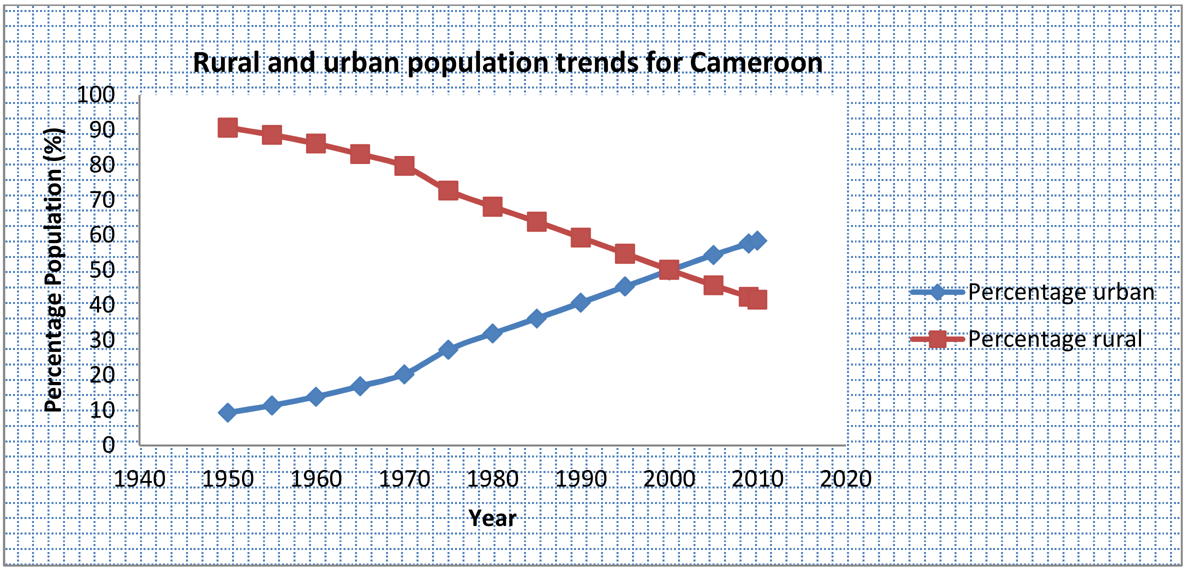


Figure 18. Rural and urban population trends for Cameroon (Source:WUP 2011)

3.4 Subsistence agriculture

Despite practicing two agriculture brands, the great majority of Cameroonian farmers are small-holders or better still subsistence farmers. With the subsistence brand, one refers to the kind of agriculture (farming) done by people who only grow enough food for themselves. Balint (2004) defines subsistence farming as a form of farming in which the family works to produce only enough goods to support the family unit, without excess intended for sale and trade. In subsistence agriculture, no extra food is produced to sell or trade. Conceptually, subsistence agriculture is easy to define, by analogy with autarky – a situation where the farm household neither sells nor buys, but consumes everything it produces and, consequently, only that (Cadot et al. 2009).

The size of the land plot required for subsistence farming depends on the number of family members who must be provided for, the type of crops being planted and the average annual yield of the land in question. It is labor intensive, and rarely is the usage of advanced technology in farming. Rather they use limited technology, such as rudimentary hand-held hoes and cutlasses are used as farmers are not financially viable to invest in modern technology. Farm sizes usually range from one hectare to about 5 hectares or sometimes more. It is also worth mentioning that most if not all of the subsistence agricultural production are depend primarily on rain. So the weather and the climate play a very preponderant role in crop productivity in SSA in general and Cameroon in particular. Subsistence farmers grow a variety of crops and keep several types of animals in order to cover a large range of dietary needs. The production statistics of some selected major staples crops such as maize, cassava, beans, groundnuts, sweet potatoes are shown on the graphs on figure 24 and accounting for two-thirds of the country's total agricultural production.

3.5 Crop types used in the study

Two crop types are used in this study. They include:- millet *(Pennisetum glaucum L.)* and sorghum *(Sorghum bicolor L.* (Moench) *)* These are the most important food crops for the approximately 6.5 million people living in this area as they serve as source of energy, protein, vitamin and mineral components. Production is rudimentary, traditional, subsistence and includes small holding farming where most of the production is consumed directly as food. Sorghum and millet are staple food crops across the Sudano-Sahelian belt and are grown by millions of resource-poor, mainly subsistence, farmers. Both crops are genetically adapted for harsh drought-prone Sudano-sahelian environment and are capable of producing grain and fodder where few other crops cannot survive. The most common delicacy made out of the 2 crops is commonly called ´´Kuskus´´ or ´´Couscous´´. Besides the provision of food to humans, and feed for livestock, the stems of both crops are used for a wide range of purposes, including: the construction of walls, fences and thatches and production of brooms, mats, baskets and shades etc.

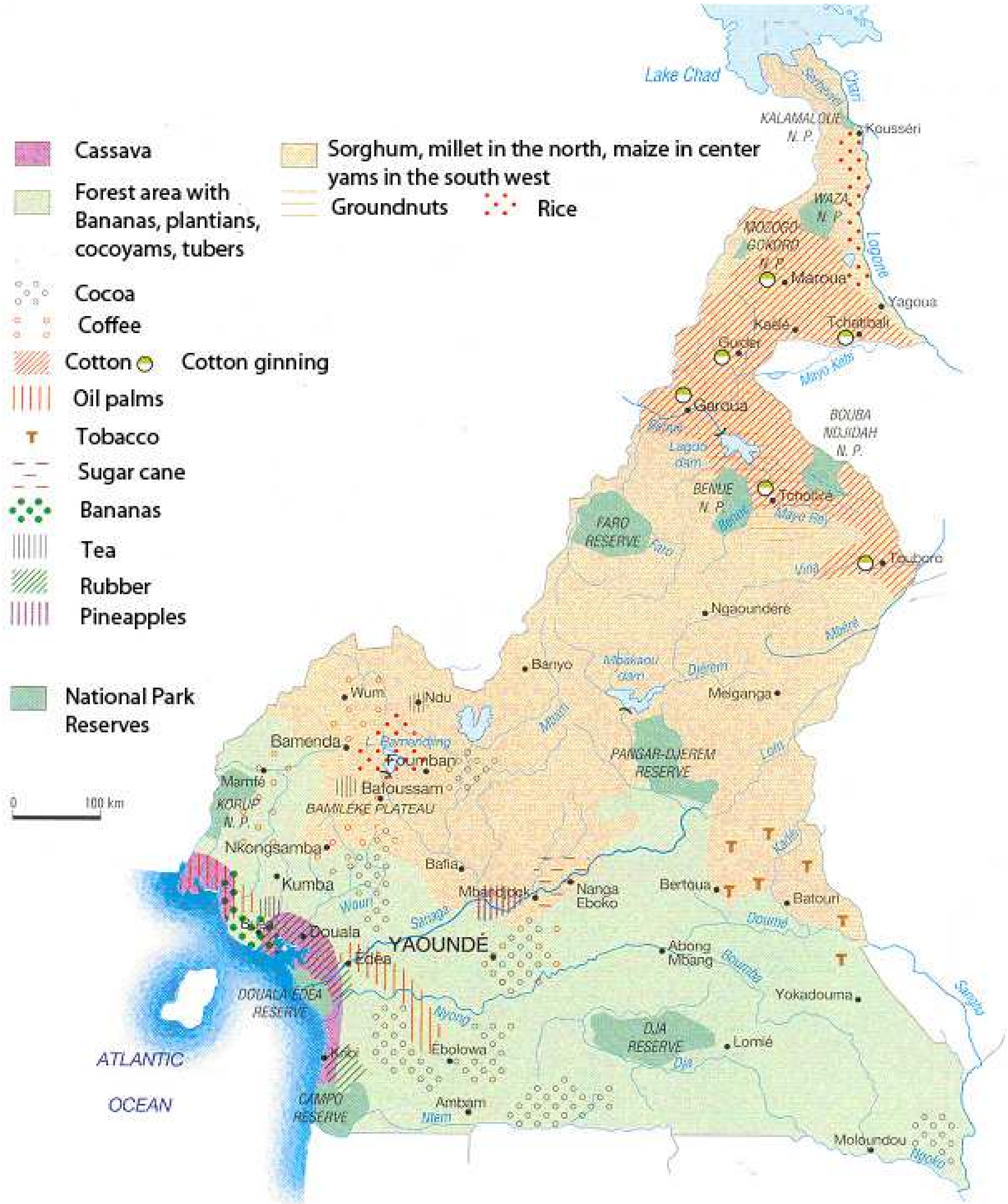


Figure 19. Agricultural map of Cameroon (Source: modified from Atlas de l´Afrique – Cameroun, Jeune Afrique 2003)

3.5.1 Millet

3.5.1.1 Agronomy and production trends

Millet is a group of high variable grasses with many small seeds. The most important is the pearly millet, finger millet, proso millet, foxtail millet etc. Pearl millet *(Pennisetum glaucum L.)* is the most common and widely grown of all millets species. Taxonomically it belongs to the plant order Poales and the family Poaceae or Gramineae. They are better adapted than most other crops to dry, infertile soils, to high temperatures, low and erratic precipitation, short growing seasons and acidic soils with poor water-holding capacity. Early millets are capable of surviving in areas with little as 300 mm or less seasonal rainfall- areas where other cereals such as maize and wheat won't survive. The grains diameter ranges from 1.0 to 1.5 mm. The plant is usually grown in farms where seeds are sowed into the soil at 3-5 cm deep and the plant grows wild. The plant ranges from 1.5 to 3 m tall wide (10) and at times they grow up to 6 m (Leder 2004).

Figure 20. The Pearl millet (*Pennisetum glaucum* L.) plant with dried grains (Source: Author)

3.5.1.2 Millet production trends and patterns

Millet is the world's seventh most important cereal, in terms of both the production and area planted. In the Sudano Sahel of Cameroon the average yield is about 0.86 ton per hectare with the total harvested area being about 395 thousand hectares (figure 21).

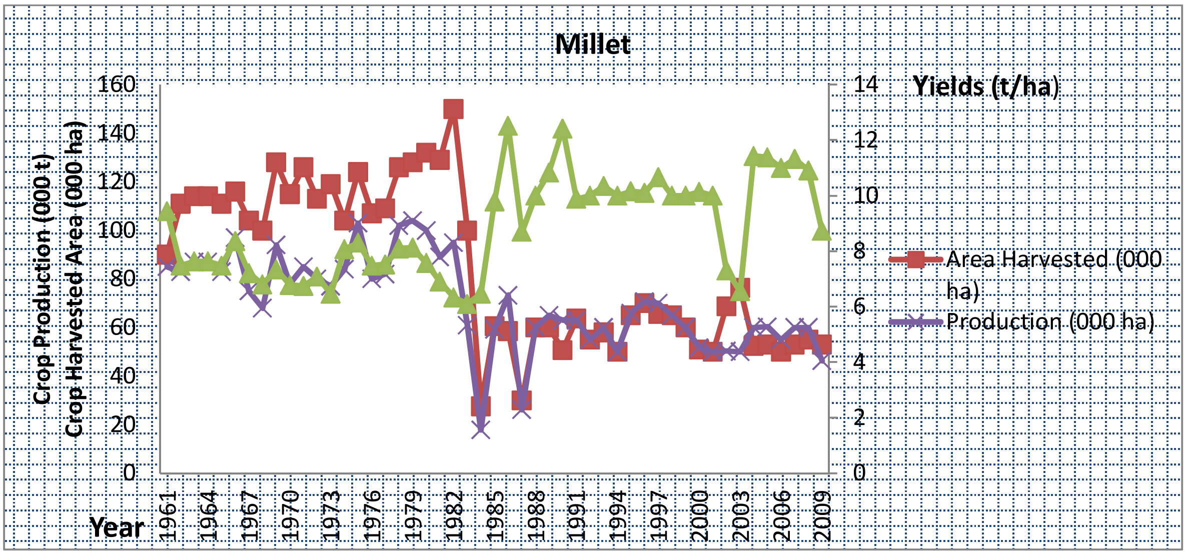


Figure 21. Time series millet production, harvested area and millet yields from 1961-2006 (Source FAOSTAT 2010)

3.5.2 Sorghum

3.5.2.1 Agronomy and production trends

Sorghum is a cereal of remarkable genetic variability. Some of the basic races are bicolor, guinea, caudatum, kafir, dura. The most common and widely grown species is *Sorghum bicolor L.*, and there exist about 10 different hybrids. Taxonomically it belongs to the plant order Poales and the family Poaceae or Gramineae. The plant is thermophilic (26-40 ^{0}C), drought resistant and grows slowly at 16-20 ^{0}C and stops growing under 14 ^{0}C. The minimum water requirement is 400 mm. Sorghum plants are 0.5 -4.0 m tall and stems are from 0.5-5 cm in diameter at the base. The seed is white, yellow or brown, usually 4-5 mm long and 2.5 -4.6 mm wide (figure 22). The plant is usually grown in farms where seeds are sowed into the soil at 3-5 cm deep where the plant grows wild. Plant development usually has three stages and includes: - emergence to floral initiation, floral initiation to flowering and flowering to physiological maturity (Leder 2004).

Figure 22. The Sorghum (Sorghum bicolor L) plant with dried grains (Source: Author)

3.5.2.2 Sorghum production trends and patterns

Sorghum on the other hand, is the world's fifth most important cereal, in terms of both the production and area planted, and accounts for about 70 % of the total annual per capital cereal consumption in the Sudano Sahel of Cameroon where the average yield is about 0.88 ton per hectare with the total harvested area being about 86 thousand hectares (figure 23).

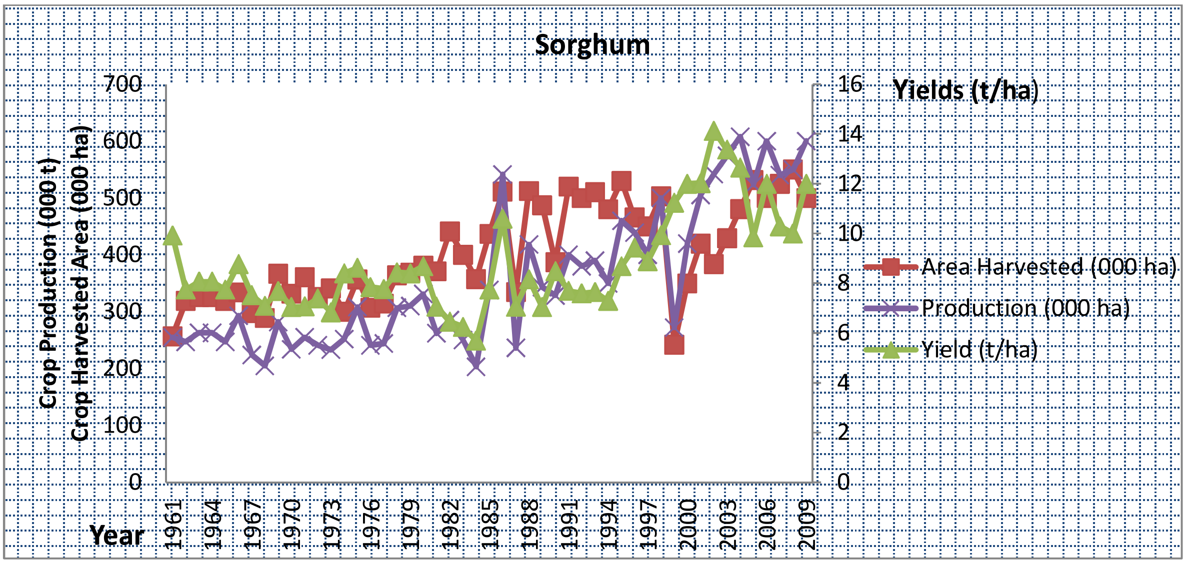


Figure 23.Time series sorghum production, harvested area and sorghum yields from 1961-2006 Source (FAOSTAT 2010)

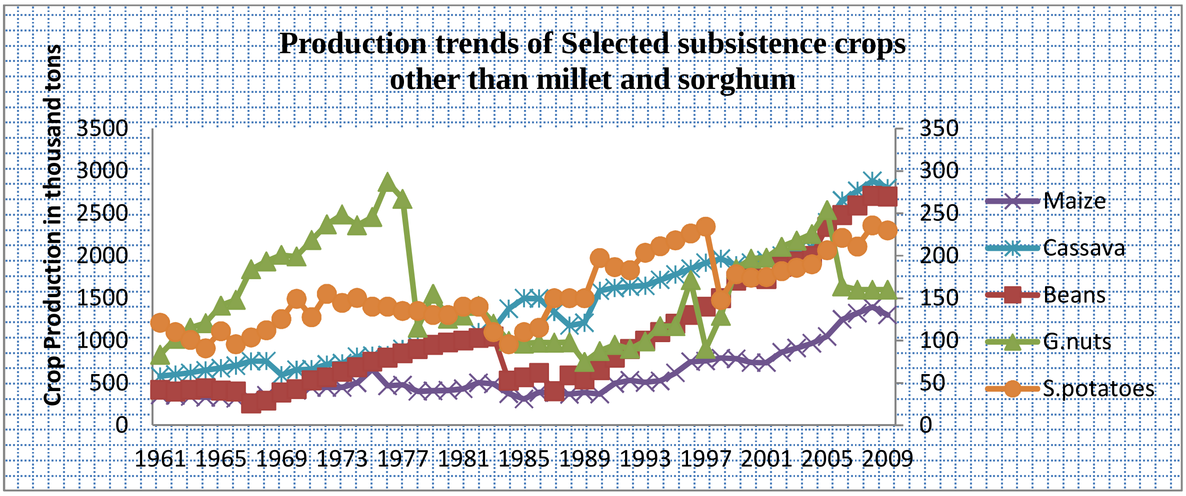


Figure 24. Time series crop production trends of some selected Subsistence crops in Cameroon. (Source: FAOSTAT data 2010, accessed 10-10-2011)

3.6 Other factors and agricultural practices determining crop productivity

Agriculture is a complex sector involving different driving parameters (environmental, economic, and social). It is now well recognized that crop production is very sensitive to climate change (McCarthy et al. 2001), with different effects according to region. In addition to climatic factors, yield is determined by some bio-physical and socio-economic factors and is placed on Table 6 below.

Table 6. Bio-physical and socio-economic affecting crop production in the Sudano-Sahel

Type	Descriptor	Details
Biophysical Factor	Soils and crop Management	Low water holding capacity, low to very low soil fertility
		Marginal soils being cultivated Occurrence of soil crust and hardsetting
	Pest and Diseases	Competition for moisture, nutrients and light
Socio-economic	Population	High population growth rate
	Land Tenure	Communal ownership leading to overexploitation
	Inputs	Very low fertilizer inputs, dependency on organic inputs
	Markets	Subsistence practices
	Credits	Lack of available credits
	Extension and Research	Non-existence and poor extension services

(Source: Adapted from Mohamed et al. 2001)

3.6.1 Bio-physical actors

3.6.1.1 Crop management, nutrient and water management

Crop output is greatly influenced by farmers' crop choices, care provided and timing of operations (Allen 1994). The choice of crops to cultivate, and even the selection of crop varieties among the same species, is crucial. Other crop management practices that have been proven to improve on yields of crops include: crop rotation, improved crop cultivars, Mixed cropping, or intercropping manuring (Shomdoe et al. 2009)

Nutrient management via compost and manure also improve the soil structure and concomitantly improves on crop yields. Fertilizer use is low in Cameroon compared to the rest of the world and it accounts for low agricultural productivity (Morris et al. 2007). The market inefficiency and the high prices account for this lowness.

As mentioned on rainfall, water is essential for crop growth and therefore productivity. When rainfall is not sufficient to cover crops´ water needs, irrigation is necessary to ensure high yields. Furthermore, irrigation also allows a decrease in production variability. Productivity in SSA is 3.5 times higher on irrigated land than on rain-fed land (Cleaver 1993)

3.6.1.2 Pest and diseases

Plant pests and diseases remain one of the major checks on crop production. The warm and moist conditions of the Sudano-Sahel in particular and the tropics in general are ideal for insects and crop diseases. Rising temperature tends to lengthen the breeding season thereby increasing the reproductive rate. That in turn, raises the number of insects attacking crop (Pimentel 1993) and subsequently crop losses. In the whole of Sub-Saharan Africa, rainfall patterns influences the migration patterns of insects (Cheke and Tratalos 2007) and as such climatic variability and change influences the impacts of this devastating pest. Climatic variability and change also affects pathogens and diseases. This may be through the warming or drought on resistance of crops to specific diseases and through pathogenicity of organisms by mutation induced by environmental stress (Gregory et al.2009).

Plant weeds are also better adapted to arid conditions than crops and provide increased competition for moisture, nutrients and light. Studies by Pimentel et al. (2001) have shown that the herbicidal control are less effective under hot dry conditions and also accumulate in soil causing environmental problems in dry areas. All these have a tremendous impact in the quality and quantity of agricultural produce.

3.7.2 Socio-economic factors

3.7.2.1 Population influence

Population pressure and growth is another significant factor that influences the influences the yields of crops in any agricultural system as a whole and the Sudano-Sahel in particular. As the population rate increases, there is the tendency of movements to marginal land areas. Farmers tend to cultivate crop land without allowing adequate resting periods for the soil to regain fertility- thus reduction in the quality and quantity of agricultural produce (Gaiser et al.2011). A detail on population influence has been extensively described in the temporal land use and land use changes described in the methodology chapter.

The human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes not fully understood. Population increase in the Sudano-Sahel and changes in regional climate often lead to land degradation, since population increases to a point that can no longer sustain the people. The presence of nomadic herdsmen in the Sudano Sahel is an indication of the likelihood of overgrazing. Overgrazing tends to remove the grass cover and vegetation, causing soil compaction, and leads to high rates of wind and water erosion. When population is so large, bush lands, shrubs and trees are cut to obtain wood for use in cooking. The slash and burn practiced in the Sudano-Sahel is also one of the causes of land degradation.

Poverty is also another cause of land degradation as it reduces the options for improving land use, and aggravates degradation. Poor nations seek income by exporting crops or minerals to developed countries. The push to increase cropland leads to unsustainable agricultural practices. Moreover, unsustainable agriculture, overgrazing, and deforestation are the result of poor planning, laws, and regulations by governments.

Another source of land degradation is land fragmentation phenomenon. Land fragmentation is also a common phenomenon in Sudano-Sahel of Cameroon, where the farmland on which households operate is usually composed of more than one parcel of land. Farmers in the study area possess very small landholdings, which are fragmented into several tiny parcels due to the ever increasing population, the inheritance laws and scarce off-farm employment opportunities.

3.7.2.2 Farm characteristics

Several farm features determine the ability and incentives to achieve high crop yields. Farm size determines the ability to take advantage of economies of scale but "most empirical studies of African agriculture find no significant economies of scale beyond a very small farm size, attributable in large part to the absence of sophisticated water control or mechanization" (Barrett et al. 2001). Tenancy terms, land tenure and water rights protection are other determinants of productivity as they provide incentives to invest in soil conservation measures and long term cropping decisions or production techniques. Property rights also facilitate access to credit by providing collateral. Land tenure arrangements in SSA are often characterized by communal or corporate ownership but they have gradually evolved toward greater individualization, especially since the colonization period (Platteau 1996).

3.7.2.3 Agricultural extension and research

This encompasses a wide range of communication and learning activities organized for rural people by professionals. It entails the application of scientific research and new technologies to agricultural practices through farmer education. Agricultural research agendas remain largely academic unless extension workers provide input in terms of the identified and as-yet unsolved field problems of the farmers. Research focusing on the technological aspects generates useful technologies while extension focuses on the acceptance and adoption of these technologies.

There is the presence of the (Institute for of Research and Agricultural Development (IRAD) in the north of Cameroon. There is also the Management Advise for Family Farms (MAFF) designed and tested since the 90s by the Institute for of Research and Agricultural Development (IRAD) within the framework of the "Le Pôle régional de Recherche Appliquée au Développement des Systèmes agricoles d'Afrique Centrale (PRASAC)"and collaboration of the "le projet Développement Paysannal et Gestion de Terroirs (DPGT)". Aimed at strengthening the farmers' decision making capacity, it moves from training on basic management and individual advice.

Agricultural extension services in the north are provided by two structures:- SODECOTTON and the National Program for Agricultural Extension and Research (NPAER). They focus on increasing productivity, thus the approach is based on the extension of new techniques. Recently, some reports have confirmed that farmlands have increased productivity as a result of some of the above services in the Sahel. Sectorial and bossy characters limit the success of the system as reported whereby farmers have been considered as passive actors whose sole role is to implement new technical recommendation.

The Ministry of Agriculture (MINAGRI) also supports structured extension program staffed by civil servants. The various facets of the extension, including farmers group, demonstration plots, credit programs, market outlets and data gathering have been integrated with varying degrees of success. Key informant though report financial and logistic constraints with MINAGRI. The also exist traces of the World Bank funded National Agricultural Extension and Training Project, based on the Training and visitation Model. These all have impacts on agricultural productivity in the Sudano Sahel of Cameroon.

3.7.2.4 Credit for farmers

The Sudano-Sahelian community is made up of poor ruralite and generally poverty ridden farming population. It is blatant that the rural farmers do not have enough to eat and poverty is prominent as most fall below the poverty line. Their access to credit is poor and limited. Positive significant relationships exist between securing of loan from credit institution and farmers performance operations (Zeller 2003). If institutional credit is made available to farmers, it could ameliorate some of the farmers’ problems such as small farm sizes, low outputs, low income and low socio-economic status. Based on the above, the government initiated different policy measures for extending financial assistance to small farmers via micro credits and self-help groups. Examples are the Food for Progress Microcredit in Mokolo where seeds, fertilizers and other agricultural additives are supplied, The “L´Organisation Credit du Sahel” that offer some credits to farmers. These all have impacts on agricultural productivity in the Sudano Sahel of Cameroon.

3.7.2.5 Inputs and markets

Without adequate inputs, local farmers often cannot meet the food needs for their families. They will need to shift from low-yielding; extensive land practices to more intensive higher practices with increased use of improve seed, fertilizers and irrigation. In Cameroon as a whole, an agricultural input such as the use of fertilizers averages less than eight kilograms per hectare. The country is trapped in fertilizer crisis and if these inputs are increased, crop productivity will certainly improve thereby bettering the livelihoods of the local farmers. Markets could also play an important role in agricultural crop productivity.

3.8 Climatic change impacts and related factors relevant to agricultural crop production

Crop production is inherently sensitive to variability in climate. Crop production in a natural setting is dependent on weather events as plants require a certain amount of water, warmth and sun to develop. With crop production in Cameroon basically subsistence and rain-fed, the weather assumes significance in nearly every phase of agricultural activity from the preparatory tillage to harvesting and storage in the region. The IPCC analysis on climate change impacts (Third Assessment Report) estimates a general reduction of potential crop yields and a decrease in water availability for agriculture and population in many parts of the developing world (see Table 7). Crop production is affected biophysically by changing meteorological variables, including rising temperatures, changing precipitation regimes, and increasing levels of atmospheric carbon dioxide. Biophysical effects of climate change on agricultural production depend on the region and the agricultural system, and the effects vary through time.

3.8.1 Incidence of extreme events

Extreme weather events include spells of very high temperature, torrential rains, and droughts. Under an enhanced greenhouse effect, change can occur in both mean climate parameters and the frequency of extreme meteorological events. Relatively small changes in mean temperature can result in disproportionately large changes in the frequency of extreme events. In arid and semiarid regions, drought is brought by lower amounts of rainfall. These effects may reduce subsequent river discharge and irrigation water supplies during the growing. Episodes of high relative humidity, frost, and hail can also affect yield and quality of fruits and vegetables (especially corn and other grains). Inter-annual variability of rainfall is a major cause of variation in crop yields and yield quality. By reducing vegetative cover, droughts exacerbate wind and water erosion, thus affecting future crop productivity. Crop yields are most likely to suffer if dry periods occur during critical developmental stages such as reproduction. In most grain crops, flowering, pollination, and grain-filling are especially sensitive to water stress. The most severe consequences of these droughts are famine. Droughts in the Sudano-Sahel are a very common phenomenon. High temperatures cause a high rate of evapotranspiration. Its incidence has increased in recent years as it occurred in 1968, 1974,1987,1990,2000, 2009 and 2011. A horrific reminder of the combined effects and impacts of droughts could be seen as thousands were left hungry, millions of livestock perished and starving children.

Excessively wet years, on the other hand, may cause yield declines due to water logging and increased pest infestations. High soil moisture in humid areas can also hinder field operations. Intense bursts of rainfall may damage younger plants and promote lodging of standing crops with ripening grain, as well as soil erosion. The extent of crop damage depends on the duration of precipitation and flooding, crop developmental stage, and air and soil temperatures.

3.8.2 Rainfall and temperature

Rainfall is a key determinant of crop growth and yields in rain fed agricultural areas as it is the main source of soil moisture. Rainfall is a key determinant of crop growth and yields in rain-fed areas. Plants assimilate water through their roots and transpire it through small pores in their leaves called stomata. Water lost via transpiration has to be replaced by water available in the soil (soil moisture) to enable plants to grow. When soil moisture is insufficient to cover the water needs of a plant, water stress occurs and plant growth is hindered. Plants have different water requirements depending on their physiology, phenological stage and the climatic zone where they are grown. Some small plants possess smaller leaf surface area than larger plants, smaller plants transpire less and thus need less water (Cothren et al. 2000). Other plants have particular water needs during critical growth stages; for instance in hot, dry, windy and sunny areas, plants transpire more, and thus have higher water requirements, than in cool, humid, cloudy and windless areas (Critchley and Siegert 1991). The water regime of crops is also vulnerable to a rise in the daily rate and potential seasonal pattern of evapotranspiration, brought on by warmer temperature, dryer air, or windier conditions.

Temperature on the other hand is a measure of the intensity of heat energy produced by solar radiation. Temperature influences plant growth as it affects physiological processes such as photosynthesis, transpiration, respiration, germination, and flowering. Air temperature is a more important for crop growth than soil temperature (Mavi and Tupper 2004). Vulnerability of crops to damage by high temperatures varies with developmental stage. Crop responses to temperature depend on the temperature optima for photosynthesis leading to growth and yield which may vary for different crops. The reproductive stage is very sensitive to temperature where low temperatures may delay anthesis which could affect final yields of crops (Bannayan et al. 2004).

When the optimal range of temperature values for a crop in a particular region is exceeded, crops tend to respond negatively, resulting in a drop in yield. The optimal temperature varies for different crops. Most agronomic crops are sensitive to episodes of high temperature. Air temperatures between 45 and 55^{o}C that occur for at least 30 minutes directly damage crop leaves in most environments; even lower temperatures (35 to 40^{o}C) can be damaging if they persist longer.

Sea Level Rise and wind surface are also some important climatic variables that affect and determine crop productivity as a whole. Rising sea levels may also lead to significant land use changes. An indirect effect on agriculture may occur if rising sea levels make population centers uninhabitable. The displaced populations will need to be housed and at least some of the housing is likely to be built on agricultural land (Inglesias et al. 2007). Table 7 summarizes the climate change related factors that have major consequences on agricultural productivity.

Table 7.Climate Change and related factors relevant to agricultural production

Climate and related physical factors	Expected direction of change	Potential impacts on agricultural production	Confidence Level of Potential impact
Temperature	Increase	Modification in crop suitability and productivity Changes in weeds, crop pests and diseases Changes in water requirements Changes in crop quality Modification in crop productivity and quality	High
		Modification in crop productivity and quality	Difference in day and night temp.
Extreme **Events**	Poorly known but significant increased temporal and spatial variability expected Increased frequency of floods and droughts	Crop failure Yield decrease Competition for water	High
Heat Stress	Increases in heat waves	Damage in grain formation Increase in some pest	High
Precipitation intensity	Intensified hydrological cycle, but regional variations	Changed patterns of erosion and accretion Changed occurrence of storm flooding and storm damage Increased water logging Increased pest damage	High
		Sea level intrusion in coastal agricultural areas	

Sea Level	Increase	and salinization of water supply	High
Atmospheric (CO2)	Increase	Increased biomass production Increased efficiency of physiological water use in crops and weeds Modified hydrological balance of soils due to C/N ratio modification Changed weed ecology with potential increased weed competition with crops Agro-ecosystems modification Lower yield increase than expected	Medium
Atmospheric (O_3)Ozone	Increase	Crop Yield decrease	Low

(Source: compiled from Iglesias et al. 2007)

3.8.3 Carbon dioxide

Carbon dioxide (CO_2) fertilization refers to plant growth enhancement resulting from increased atmospheric CO_2 concentrations (Allen 1994). CO_2 has an indirect effect on plants as it changes the climate through the greenhouse effect. It also has a direct effect on plants by increasing photosynthesis and reducing transpiration. Photosynthesis enables plant growth through the conversion of CO_2into glucose and oxygen (Walker 2006). CO_2 is assimilated through stomata, which at the same time allow water to evaporate from the plant. Plants adapt stomata closure in order to balance the loss of water and the intake of CO_2. A higher concentration of CO_2 in the atmosphere enables plants to assimilate the required amount of CO_2 at a faster rate through smaller stomata opening and thus reduces the level of transpiration. The combination of increased photosynthesis and reduced transpiration increases crop water use efficiency, which reduces crop vulnerability to water stress and therefore results in higher crop yields (Adams 2007).

Plant reactions to changes in CO_2 concentration differ by species and variety but follow similar carbon fixation paths. Plants are classified into C_3 and C_4 categories depending on their dependence on CO_2. C_4 plants, such as maize, sorghum and millet, are more efficient at assimilating CO_2 than C_3 crops such as cassava (Lawlor 1997). CO_2 increases are therefore especially beneficial for C_3 crops. Laboratory experiments simulating the effect of a doubling in CO_2 on plants suggest yield gains ranging from 10% to 50% for C_3 crops and from 0% to 10% for C_4 crops (Maunder 1992). However, increases in CO_2 do not produce proportional increases in crop productivity; other factors play a significant role. While experiments with increased concentrations of CO_2 under controlled conditions have been shown to significantly increase yields of crops, these increases have occurred when other factors such as moisture supply, nutrients and pest and disease incidence have not been limiting (Adams 2007). In practice, an insufficient supply of water or nutrients or greater pest/disease attack or competition from weeds is expected to frequently negate the fertilizing impact of increased CO_2 concentrations in the atmosphere. Since weed growth may also be enhanced by increased CO_2, changed weed ecology may emerge with the potential to increase weed competition with crops.

4.0 Climate change adaptation and mitigation

4.1 Etymology of adaptation and mitigation

The term "adaptation" is derived from the Latin word *adaptare* meaning "to fit" and carries with it variations in meanings for all manner of disciplines. "The layman, the biologist, the physician, and the sociologist use the word, each in his own way, to denote a multiplicity of genetic, physiologic, psychic and social phenomena, completely unrelated in their fundamental mechanisms" (Dubos 1965). The Ecologist for instance, frequently refers to adaptation as the changes by which an organism or species becomes fitted to its environment (Lawrence 1995). In the social sciences, cultural adaptation has referred to adjustments by individuals and the collective behavior of socio-economic systems (Denevan 1983). The word has its very core meaning in adjustment to new circumstances, or to make suitable for a purpose as its Latin origin *adaptare* "to fit". Hence in its broadest descriptive terms, adaptation can be reactionary as in adjusting to new conditions, or precautionary with respect to making something suitable for a purpose.

The word "mitigation" on the other hand is of Latin origin, *mitigare* meaning "to alleviate". In the context of climate issues, it usually means the alleviation or reduction of the anthropogenic part of climate change. The term "mitigation measures" refers above all to methods and technologies for reducing greenhouse gas emissions. There are also other ways in which humans influence climate, e.g. by land use change and the resulting change in the ability to reflect solar radiation. Measures alleviating this kind of anthropogenic influence on climate may also be considered under the term "mitigation" (BMBF 2007)

4.2 Prelude to adaptation and mitigation

Adaptation to climate change is not a new issue as it no longer needs justification although its explanation is required. Human societies have always dealt with climatic variability, surviving average and extreme climate events such as the ice ages, to establish societies in diverse areas of the world. However adaptation to climate change differs from past experiences in that anticipated rapid pace of climate change will likely test the coping and adaptive capacity of human population, and the fact that the present scientific capacity enables humans to adapt and mitigate in anticipation of future change as opposed to only reacting to current conditions and engaging in planning based on historical climatic trends and risk. Adapting to climate variability and change is important both for impacts assessments (estimating which adaptations are likely to occur (impact assessment) as well as advising on or prescribe adaptation (policy development).

On the basis that some climate change is already inevitable particularly in the Sudano-Sahel, it is necessary to think about and act on adaptation and mitigation now. The science is clear- climate impacts are felt today, and greater impacts are unavoidable tomorrow. Adaptation and mitigation are essential in reducing human and social costs of climate change, and to development and poverty alleviation. This chapter initially provides general description of some of the concepts and definition of adaptation and mitigation. Understanding adaptation and its characteristics and also discusses key prerequisites for effective adaptation and distinguishes the different kinds of adaptation. Current areas of discussion in adaptation as well as stakeholders involved in adaptation, and mitigation are also discussed, with mitigation concepts and potentials taken into considerations.

4.3 Defining adaptation and multidimensional concepts for climate change

Analyses of adaptation to climatic change have involved scholars both within and outside climate change community such that some basic concepts have been broadly developed. The connection between climate change and adaptation is commonly associated with the biological/Darwinian evolutionary doctrines where in “The Origin of Species” (Darwin 1859) the point is made clear that climate is one of the most important parameter that exist in determining the population of a species. It is explained that the action of the climate increases the severity of the struggle for existence and therefore accelerates evolution (adaptation). Nevertheless adaptability should not be confused with the evolutionary process of adaptation. The later involves the ways humans and other animals employ learning rules to adapt their behavior to environmental conditions. (Sanderson and Sardar 2007).

A plethora of definitions pertaining to adaptation have been proposed in climate change literature and are synthesized in the following developments below. The most authoritative definition of adaptation is found in Chapter 18 of the Working Group II documents of the Third Assessment

Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), where adaptation is defined as:

> *"Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change" (IPCC 2000).*

There are other definitions that are also often used and below are a few more examples: "Adaptation to climate change is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provide" (Burton 1992).

"Adaptation to climate change includes all adjustments in behavior or economic structure that reduce the vulnerability of society to changes in the climate system" (Smith et al. 1996).

"Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in condition" (Watson et al. 1996).

"Adaptation is the adjustment in individual, group and institutional behavior in order to reduce society's vulnerabilities to climate" (Pielke 1998).

"Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change" (Smit et al. 2000).

Other extensive definitions of climate change adaptation from various governments such the United States (Environmental Protection Agency) the European Union and the United Nations Development Program (2005) have been placed in the box 1.Almost uniformly; each of these government sources relies on an exact replication or slight modification of the definition used by the IPCC (2001)

Box 1.Definition of adaptation from various governments

Government of the United States of America (2006):

Adaptation is defined in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Planned adaptation refers to strategies adopted by society to manage systems based on an awareness that conditions are about to change or have changes such that action is required to meet management goals. The purpose of adaptation strategies is to reduce the risk of adverse outcomes through activities that increase the resilience of ecological systems to climate change stressors (Environmental Protection Agency 2006).

The European Union (2007):

Adaptation aims at reducing the risk and damage from current and future harmful impacts cost-effectively or exploiting potential benefits. Adaptation measures can be anticipatory or reactive. Adaptation applies to natural as well as to human systems. Ensuring the sustainability of investments over their entire lifetime taking explicit account of a changing climate is often referred to as 'climate proofing' (EU 2007).

United Nations Development Program (2005):

Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed, and implemented. (UNDP 2005 in Livena and Tripak, 2006)

4.4 Adapting to climate change

The above definitions have much in common. They all refer to adjustments in a system in response to climate stimulus, indicating differences in scope, application and interpretations. The definitions depict that the adaptation process can take the most diverse forms depending on where and when it occurs and on who is adapting to what. Bosello (2010) identified three dimensions from the definition:-

The subject of adaptation (who or what adapts)

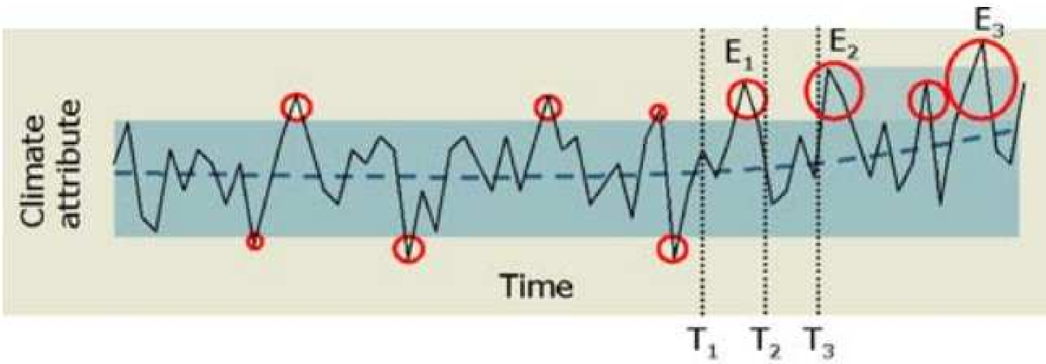
The object of adaptation (what they adapt to)

The way in which adaptation takes place (how they adapt)

The object of adaptation pertaining on what to adapt actually considers adaptation in the context of the various manifestations of climatic stimuli. These are generally referred to as doses, stresses, disturbances, hazards, and perturbations (Burton 1997). Stimuli for adaptation are sometimes expressed as climate or weather conditions (e.g. annual average precipitation, or daily precipitation), sometimes as ecological effects or human impacts of the climatic conditions (e.g. droughts, crop failure or income loss), and increasingly as the risks and perceptions of risk associated with climatic stimuli or the opportunities created by changing conditions (Smit et al. 2000). Thus the phenomena to which adaptation are or might be made need to be specified according to the climate characteristics which are relevant (e.g. temperature, precipitation) and their connection to the system which adapts. For example, an adaptation in agriculture may be in response to the sequence such as temperature and precipitation conditions, which result in drought (magnitude and /or frequency) which influence crop yields and having consequences for income and livelihood.

The next pertinent question from the definition is the subject of adaptation on who or what adapts and this could be represented by the sensitivity of the system. Where the diversity of adaptation activity could be motivated by current and future hazards, including observed and expected changes in average climate, climate variability and climate extremes. The system might be individuals or community, region or country or about the entire globe. Adaptation at the levels of farmer’s fields might involve planting new hybrids or taking out insurance; and at a regional or global scale, adaptation may relate to changes in the number of farms or modifications to a compensation program; or may involve a shift of international food trade at the global level (Smit et al. 2000). A population might at one point turn to adapt to non-climatic conditions as well as that occur against a background of environment, economic, political and cultural conditions that vary substantially across regions.

Still branching from the various definitions of adaptation, the question that arises is how does adaptation occurs? This is explained in the figure 25 after Füssel (2007). Where it shows a hypothetical time series of climate attribute, for example precipitation, and the target community is assumed to be well adapted to a given range of this climatic variable, denoted as the coping range, but it is vulnerable to climatic conditions outside this coping range. An insufficient precipitation implies droughty conditions that may cause crop damages and failure, where as too much precipitation may cause river flooding. In the period up to T_1, climate largely remains within the coping range, and the community is preparing to accept the minor damage caused by the occasional slight exceedance. Shortly after T_1, the climate event E_1 exceeds the coping range substantially, causing significant damage.



Time series of climate attributes
Trend in mean value of climate attribute
Coping range (before/after adaptation)
Exceedance of coping range (vulnerability)

Figure 25. Hypothetical example for the timing of planned adaptation(Source: Füssel 2007).

From the above example from Füssel (2007) it suggest that the considered climate variable is indeed increasing (and will continue to do so for the foreseeable future) because of anthropogenic greenhouse gas emissions. As a result the community makes a decision at T_2 to extend their coping range upwards (e.g. changing in planting dates,). Implementation of this adaptation takes until T_3, when the coping range is effectively extended. Soon after T_3, another extreme event E_2 occurs. This event is even stronger than E_1 but still within the extended coping range. Hence adaptation has prevented the substantial damage that would have occurred otherwise. As climate continues to change, however, an even more extreme event E_3 occurs, which exceeds even the extended coping range, causing substantial damage despite previous adaptation. At this point, the community is faced with the question whether to accept the apparent increased risks or whether to undertake further costly adaptation.

Lessons that could be learnt from this hypothetical illustration is that adaptation needs arise often but not always from extreme events rather than from average climatic conditions. Secondly when vulnerability is linked to extreme events, natural climate variability and anthropogenic climate change need to be considered jointly, because risks arise from the combination of the two. Lastly the above paves a way for adaption to be addressed into different types and forms and will be discussed in the next headings.

4.5 Adaptation types and forms

Adaptations come in a huge variety of forms and there are many ways of classifying it. These types (i.e., how adaptation occurs) have been differentiated according to numerous attributes (Carter et al. 1994; Smithers and Smit 1997; UNEP 1998; Leary 1999; Bryant et al. 2000; Reilly and Schimmelpfennig 2000). The commonly used classification schemes could be based on attributes such as purposefulness or intent, timing, agents as well as temporal scopes. These are all discussed in this sub chapter as shown on table 8.

Table 8. Possible adaptation classification

Concept or Attribute Based on	**Classification type**
Purposefulness/ Intent	Autonomous adaptation
	Planned adaptation
Timing	Anticipatory (Proactive adaptation)
	Reactive adaptation
Agents	Private adaptation
	Public adaptation
Temporal Scope	Short-term adaptation
	Long-term adaptation

(Source: modified from Malik 2010)

4.5.1 Classification based on intent/ purposefulness:

Two forms of adaptation have been distinguished based on intent and purposefulness. They include Autonomous or spontaneous as well as planned adaptation respectively. Autonomous or spontaneous adaptation are considered to be those that take place – invariably in reactive response (after initial impacts are manifest) to climate stimuli – as a matter of course, without the direct intervention of a public agency. Adaptation does not constitute a conscious response to climatic stimuli, but triggered by ecological changes in natural systems and by market or welfare changes in human systems (Malik et al. 2010). Planned adaptation on the other hand is the result of deliberate policy decision, based on the awareness that conditions have changed or are expected to change, or are about to change and that some form of action is required to return to, to maintain, or to a desired state (IPCC 2007).

4.5.2 Classification based on timing

They are defined based on the timing of the action relative to the climate stimulus depending on if adaptation takes place before and after impacts are observed (IPCC 2001). Two forms of adaptation that have been distinguished include the anticipatory or proactive adaptation and reactive adaptation.

Proactive adaptation or Anticipatory adaptation involves long-term decision making which improves our ability to cope with future climate change. It is more frequently reported from developed or high-income countries and is more likely to be stimulated by long-term changes in climatic averages or isolated extreme events. In addition, long-term proactive planning was more likely to be undertaken by higher levels of government and involve non-resource sectors (e.g., infrastructure, transportation). Common adaptation actions included preparing for projected impacts, monitoring, and increasing awareness, building partnerships, and improving learning.
Reactive adaptation refers to the immediate response to climate change and takes place in response to the consequences of a particular event. This form of adaptation takes place after impacts have been observed and is often used to regain stability. It is sometimes not the best response when our past understanding doesn't correspond to current environmental and socio-

economic conditions and this form of adaptation is often more costly than the proactive adaptation.

4.5.3 Classification based on agents

Two forms of adaptation have been distinguished based on agents. They include private and public adaptation respectively. Private adaptation is the form initiated and implemented by individuals, families, households or private companies. It is usually in the actor's rational self-interest. Public adaptation on the other hand is initiated and instituted by governments at all levels and are usually directed at collective needs.

4.5.4 Classification based on temporal scope

Based on temporal scope, short-term and long-term adaptation can be distinguished. This therefore implies that some adaptation measures are appropriate in the short-term while others are more proper in the long-term. In the former, decision maker's response to climate change is constrained by a fixed capital stock, so that the principal options available are restricted to variable inputs to production (Stern 2007). For example, changing crop varieties or adjusting planting/harvesting dates are short-term measures that can be used by farmers. In the latter, decision maker can adjust capital stock in response to climate change. A typical example of a long-term adaptation measure in climate change could be transforming agricultural production system itself into a more resilient system to climate change such as integrated farming is a longer term adaptation strategy. Long-term solutions also include insurance and banking.

4.6 Some criteria for evaluating adaptation options

Due to the wide range of adaptation options, it is important to evaluate these in order to determine which adaptation actions should be promoted or implemented under specific circumstances (Dolan et al. 2001). Planned (anticipatory) adaptations can be evaluated using methods such as cost benefit analysis, cost effectiveness analysis or multiple criteria evaluation. Evaluation of adaptations to climate change needs to be considered as part of an ongoing assessment of choices in a context of multiple risks. "Evaluations are intended to assess the overall merit, suitability, utility or appropriateness of potential adaptation strategies or measures"

(Dolan et al. 2001). Once an adaptation strategy has been evaluated, the measure that yields the greatest net benefit should be chosen.

Various criteria such as effectiveness, flexibility, economic efficiency, social acceptability, timeliness, equity, institutional compatibility, farmer ability to implement, and net benefits independent of climate change, are used in literature to evaluate adaptation options (Adger et al. 2007). These criteria are context specific and are based on competing values as their importance varies from context to context. For instance effectiveness relates to the capacity of an adaptation action to achieve the expected / target objectives and can be measured by robustness to uncertainty and flexibility, that is, ability to change in response to altered conditions (Speranza 2010). Flexibility on the other hand refers to the ability of an adaptation to perform well for a range of likely climate changes. This is important given the uncertainties in climate change, so that adaptations can accommodate "adjustments as new information becomes available, or as experience is gained". According to Dolan et al. (2001), a flexible adaptation option in agriculture is one that is functional in the light of unforeseen climate changes and effects. For example, planting crop varieties that are tolerant to a wide range of climate conditions is considered more flexible than planting crop varieties that are productive in very particular climate conditions (Speranza 2010).

4.7 Adaptation issue at international arena

4.7.1 Adaptation in the United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC was accepted at the United Nations Conference on Environment and Development at Rio in 1992. Although the main aim of the UNFCCC is to “achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UN 1992), a number of articles refer to the need for adaptation to climate change. Article 3.3, although it does not mention the word adaptation, still states that “The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects”. With regard to the implementation of adaptation measures as part of a response strategy, the UNFCCC, through Article 4.1(b) commits par ties to “formulate, implement, publish and regularly update national and, where appropriate, regional programs containing measures to mitigate climate change…and measures to facilitate adequate adaptation to climate change" (UN 1992). Article 4.1(e) continues by saying that all par ties should "cooperate in preparing for adaptation to the impacts of climate change" and it recognizes the vulnerability of Africa as it commits par ties to "develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods" (UN 1992).

Under the United Nations Framework Convention on Climate Change (UNFCCC), discussions on the question of adapting to climate change in developing countries have been based on the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). During the 1990s, most of the scientific research and most of the negotiations concentrated on mitigation. This resulted in the formulation of the Kyoto Protocol in 1997. There was a divergence between the priorities of the developed countries, which were to reduce greenhouse gas concentrations (also the main objective of the UNFCCC), and those of the LDCs, which were to reduce their vulnerabilities to climate change, which is primarily caused by the emission of greenhouse gases from the developed countries (Apuuli et al. 2000). In 2001 the parties to the UNFCCC accepted the Marrakech Accords at the seventh Conference of the Parties (COP 7). The Marrakech Accords looked at, amongst other things, the need for the LDCs to have more support from the international community regarding climate change, and the need to emphasize the importance of adaptation to climate change. In the Marrakech Accords a LDC Expert Group was established. This group consists of 12 experts who have the appropriate expertise and competence to assist in the development of the National Adaptation Program of Action (NAPAs)

At the 11th Conference of the Parties (COP 11) held in Montreal, Canada in 2005, a work program on adaptation in development countries was adopted titled the "Five-year program of work on scientific, technological, and social aspects of impacts, vulnerability, and adaptation to climate change" (Five-year Work Program on Adaptation). At COP 12 held in Nairobi, Kenya in 2006, the "Nairobi Work Program" specifying concrete contents and the schedule of activities was agreed upon. Discussions were held on vulnerability and adaptation to climate change in developing countries, as well as on the ways the international society can assist to alleviate the situation. Besides, discussions were held on the "Adaptation Fund," which is planned to receive funds mainly from a 2% share of the proceeds from the Clean Development Mechanism (CDM) for further international negotiations, in parallel with discussions on the "Five-year Work Program on Adaptation." At COP 13 in Bali, Indonesia in 2007, a workshop was held on the planning and implementation of adaptation (UNFCCC), resulting in discussions on the planning and implementation of adaptation in each sector and at each level, and the demonstration of relevant good practice. The discussions at COP 13 again indicated the importance of adaptation at community levels and of indigenous knowledge and at the COP 14 in Poznan, the finishing touches were put to the Kyoto Protocol's Adaptation Fund, with Parties agreeing that the Adaptation Fund Board should have legal capacity to grant direct access to developing countries. The Copenhagen Accord recognizes the "urgent" need for "enhanced action and international cooperation on adaptation," at the COP 15. In the COP 16, the Cancun Adaptation Framework with the objective of enhancing action on adaptation, including through international cooperation and coherent consideration of matters relating to adaptation under the Convention (UNFCCC 2011).

The COP 17 was held in Durban, South Africa, and it delivered a breakthrough on the international community's response to climate change. The negotiations advanced, in a balanced fashion, the implementation of the Convention and the Kyoto Protocol, the Bali Action Plan, and the Cancun Agreements. Finally, in the COP 18 held recently in Doha Qatar, the so called Doha Gateway was reached, whereby governments consolidated the gains of the last three years of international climate change negotiations and opened a gateway to necessary greater ambition and action on all levels. Among the many decisions taken, governments of developed countries reiterated their commitment to deliver on promises to continue long term climate finance support to developing nations, with a view to mobilizing USD 100 billion annually from a variety of sources both for adaptation and mitigation by 2020.

4.7.2 Actors for adaptation to climate change

This section takes a brief look at some of the key actors and the roles they play in climate change adaptation. These key actors include the United Nations Framework Convention on Climate Change (UNFCCC), the National Adaptation Programs of Action (NAPAs) and the Nairobi work program (NWP). Adaptation to climate change was first highlighted in the 1994 UN Framework Convention on Climate Change (UNFCCC), which is the global guiding policy document to which nearly every country in the world has committed itself. It is through the UNFCCC, its 1997 Kyoto Protocol, and related activities that climate change has raised to the top of political agendas worldwide. Alongside these bodies, there are other actors that have a strong influence over development processes and are best placed to reach the local levels and are actively engaged in facilitation and implementing efforts in adaptation. These actors include other UN agencies, development assistance agencies, international financial institutions, multilaterals like the OECD, the WTO, the ADB, the private sector, local or municipal governments, development NGOs, and community based organizations (CBOs) and national governments. These organizations all have the task of integrating adaptation considerations into policies, programs, and project and deliver support to specific areas reflective of their individual mandates, assets and capacities.

National adaptation programs of action (NAPAs) provide a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage. The steps for the preparation of the NAPAs include synthesis of available information, participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase due to climate change, identification of key adaptation measures as well as criteria for prioritizing activities, and selection of a prioritized short list of activities.

The Nairobi Work Program (NWP) is undertaken under the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC. Its objective is to assist all Parties, in particular developing countries, including the least developed countries and small island developing States to: improve their understanding and assessment of impacts, vulnerability and adaptation to climate change; and make informed decisions on practical adaptation actions and measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability.

4.7.3 Hotspots on adaptation to climate change

With many numerous questions about adaptation, the topical issue nowadays is on local-level adaptation involvement as well as the integration of adaptation into existing programs and projects in order to create climate change awareness. Local-level adaptation, and particularly community-based adaptation and mainstreaming, are areas of growing interest, in part because it is at the local level that the benefits of adaptation will be the most obvious. Adaptation at the local level has clear links with development, as many of the actions that are considered necessary for households and individuals to adapt to climate change are also high on the sustainable development agenda

Community-based adaptation to climate change is a community-led process, based on communities' priorities, needs, knowledge, and capacities, which should empower people to plan for and cope with the impacts of climate change A community-based adaptation (CBA) is very significant since it is a bottom-up approach whereby a community is positioned as the main entity to implement adaptation and is considered to be the subject of projects including competence development and technology transfer to improve adaptive capability. Based on the idea of CBA, examinations of approaches to vulnerability and adaptation to future climate change are conducted through assessments of risks and vulnerability that communities currently face.

4.7.3.1 The Community-based adaptation process

At the project level, CBA initiatives may either start by identifying the communities or these may request support themselves. Along this, cooperative work between local partners as representatives for the people in a community with international development NGOs and donors can be another perspective. The CBA processes are divided into four stages that include: - analysis, design, implementation and monitoring/up scaling. They are described as shown as shown on figure 26.The analysis stage is to set the context of the CBA. It compromises the collection, organization and production of data on the project background. (Baas and Ramasamy 2008) In order to understand needs and opportunities and hence derive an appropriate design of the project, important information concerning social, economic, environmental and political factors which are influencing livelihoods need to be collected and analyzed (Christian Aid 2009). This is commonly done by environmental analysis, stakeholder analysis, needs assessment, livelihood analysis and institutional assessment hazards on livelihoods and ecosystems. Additionally, existing coping strategies are examined on their effectiveness and sustainability regarding prospected climate scenarios. Potential opponents with policies and programs hindering CBA, but also partners are identified and priorities set. Furthermore, vulnerability of social groups, livelihoods and economic sectors to climate change is assessed, taking differences based on heterogeneous groups into account (CARE International 2010).

After the project analysis, the project design follows. Using previously obtained information and recommendations, the scope of the project is set; aims of the project are defined and adaptation strategies at individual, household and community level are identified to realize stated aims. However, with constant uncertainty in the work of adaptation, project designs are always process-oriented and flexible enough to react to a changing context and new priorities emerging over time. Therefore, the design process is documented very carefully to facilitate a better implementation. It is important that the design process is participatory, including all stakeholders from governments, partner organizations to target communities and representatives of vulnerable men and women. Also, scientists and technical experts are consulted, taking into consideration priorities and issues identified during the analysis (Siles 2004).

The implementation phase follows, where project resources are consumed, stakeholders are actively integrated into the processes; capacity of staff and partners is developed, along with continuous monitoring of the project and adaptation to changing conditions (CARE International 2010). Afterwards, monitoring and necessary adjustments of the project are pursued. All adjustments hereby intend to minimize negative impacts of changes and support desired project outcomes. Therefore, appropriate mechanisms for the monitoring context are established. These include the monitoring of climate variables via information of meteorological institutions, socio-economic trends and changes in the bio-physical environment. Moreover, the accessibility and availability of natural and financial resources as well as population dynamics and changes of behavior patterns are ought to be monitored along with current policies and the prevailing political situation (CARE International 2010).

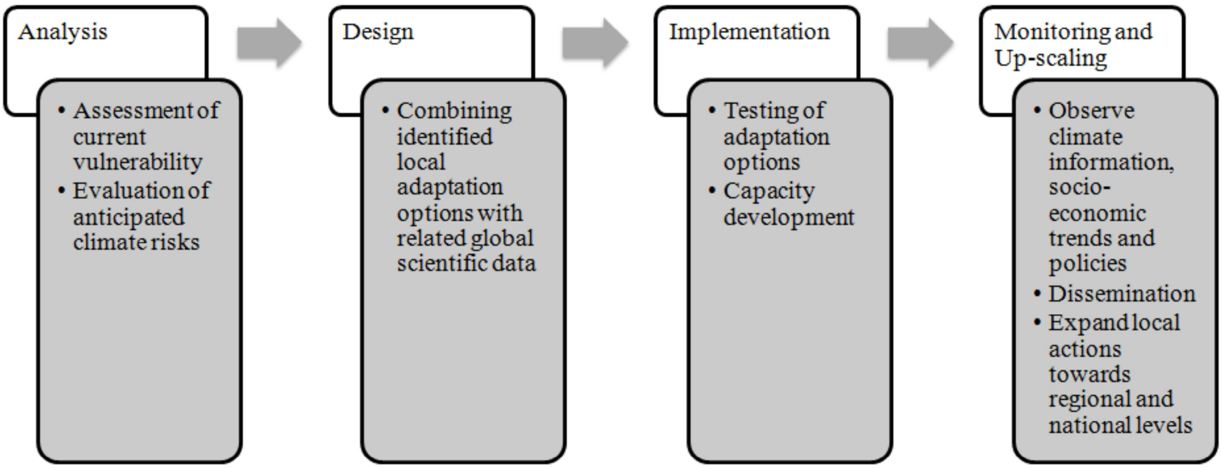


Figure 26. The CBA Process (based on CARE International 2010)

Mainstreaming continues to be another sub-theme to emerge in the adaptation debate. Although tools and guidelines have been established for 'climate-screening' donor development portfolios, there are still few useful tools for national governments to use for integrating adaptation into development agendas, plans and policies. Mainstreaming takes place on various levels. It can be integrated into development projects; it can be incorporated into development programs; and it can mean that staff members are all informed about climate change. It can also mean retrofitting initiatives to ensure that they are 'climate-proof', i.e. do not fail to take into account changes in conditions (ecosystems, politics, etc) that could result from climate change.

4.8 Climate change mitigation

Mitigation is a response strategy to global climate change, and can be defined as measures that reduce the amount of emissions (abatement) or enhance the absorption capacity of greenhouse gases (sequestration). It refers to any strategy or action taken to remove the GHGs released into the atmosphere, or to reduce their amount. IPCC (2007) defines mitigation as the technological change and substitution that reduce resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce GHG emissions and enhance sinks. To design an effective mitigation strategy, knowledge of the GHG emission pattern, available mitigation options, role of technology and market-based mechanisms is very crucial. Before discussion the GHG mitigation options and potentials, it would be adequate to consider the agricultural contribution to the GHG emissions.

4.8.1 Options for GHG mitigation in agriculture

Climate change is the result of an increase in the concentration of greenhouse gases (GHG) like carbon dioxide, nitrous oxide, and methane. With the global GHGs standing at 50Gt CO_2 equivalent, agriculture contributes to 13 percent while Land Use Change and Forestry 19 percent. Implying an approximately 6500 $MtCO_2$ equivalent and 9000 Mt CO_2 equivalent respectively. Agriculture contributes more than half the world's emissions of nitrous oxide and methane and is shown in the bar chart on figure 27.

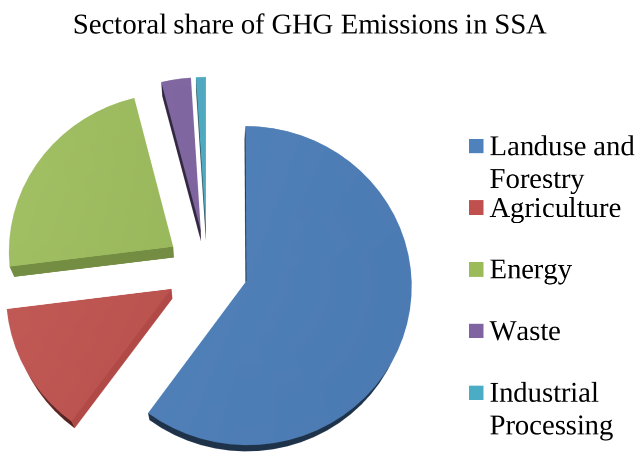


Figure 27. Sectoral Share of Greenhouse Gas (GHG) emissions in Sub-Saharan Africa (Source: adapted from Bryan et al. 2008).

While CH_4 and N_2O emissions are far less in quantity in the atmosphere, they have a much more potent impact on the climate. Methane and nitrous oxide are 23 and 310 times more potent than carbon dioxide, thus have a higher Global Warming Potential (GWP)1. The emissions from the agricultural sector are primarily methane, nitrous oxide, making the agricultural sector the largest producer of non-CO_2 emissions. About 60 percent of the total global non- CO_2 emissions in 2000 came from agriculture (WRI 2008). If indirect contributions (e.g land conversion, fertilizer production and distribution and production and farm operations) are factored in, some scientists have estimated that the contribution of agriculture could be as high as 17-32 % of global anthropogenic emissions (Bellarby et al.2008).

Africa´s contribution to climate change through GHG emissions is insufficient compared to large emitters with exceptions generated through land use changes. Africa as a whole produces less than 4% of the world's total greenhouse gases; this is by far less than the countries in North America and Europe. An average African for instance generates 13 times less GHGs than his counterpart in North America.

Virtually all the carbon released into the atmosphere from land use changes is equivalent to 8.5GtCO_2 equivalent[2] and is said to come from the tropics, with Africa said to contribute an approximate 20 percent of the load (1.7GtCO_2 equivalent). In SSA, agriculture´s share of the total emission stands at 13 percent (approximately 845MtCO_2 equivalent) and 80 percent for land use Change and Forestry emissions (approximately 5400 MtCO_2 equivalent) (calculations based Smith et al. 2008).

Agricultural sources such as animal husbandry, manure management and agricultural soils account for about 52% of global methane (CH_4) and 84% of global nitrous oxide (N_2O)

[1] Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming.

[2] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years).Equivalent CO2 (CO2e) is the concentration of CO2 that would cause the same level of radiative forcing as a given type and concentration of greenhouse gas. 1 Gt (Giga tonne) = 1000 million tonnes. 50 Gt CO_2-eq is equal to 50000 million tonnes CO_2-eq.

emissions (Smith et al. 2008). In the past, deforestation and intensive agriculture (e.g., cultivating grasslands) have contributed significantly to the increase in atmospheric carbon dioxide (CO_2), and it is estimated contribution to the global GHG is about 25 % (Lal 2004).

4.9 Sustainable agriculture in climate change adaptation and mitigation

In confronting SSA as a whole and Cameroon´s agriculture in particular in times of climate change, the million dollar questions that arise are if the farmers are able to adapt to the adverse impacts and concomitantly what ways in which the current agricultural management practices could mitigate the impacts by increasing storage of carbon and reduce emissions of carbon dioxide, methane, and nitrous oxide. Sustainable agriculture (SA) has various names like ecological agriculture (EA), agro ecology, or biological agriculture and provides a viable option since it has the potential to do both. Ecological agriculture also depends on the knowledge and skills of farmers and their locally-adapted practices to innovate in the face of uncertainty (Pretty and Hine 2001). In the course of this write up, the term sustainable agriculture shall be used interchangeable with ecological agriculture[3]. The overarching priority will imply therefore putting the idea of sustainability at the center of Sub Saharan agricultural practices rather than at the edge (Techoro 2012; Pretty 2006). This form of agriculture is biodiversity-based (Ensor 2009), depending on and sustaining agricultural biodiversity. It has additional benefits beyond its direct relevance for mitigation and adaptation to climate change and climate variability, as it helps to increase food security and water protection (Techoro 2012).

Conservative estimates of the total mitigation potential of SA amount to 4.5-6.5 Gt CO2eq/yr (of ca. 50 Gt CO_2eq total global greenhouse gas emissions). Depending on agricultural management practices, much higher amounts seem however possible. SA compliments emission reduction efforts with its major sequestration potential, which is based on the intensive humus production (requiring CO_2) of the fertile soils. In comparison to conventional agriculture, SA also directly contributes to emission reductions as it emits less N_2O from nitrogen application (due to lower

[3] Ecological Agriculture or Sustainable Agriculture is "a holistic production management system that avoids use of synthetic fertilizers, pesticides and genetically modified organisms, minimizes pollution of air, soil and water, and optimizes the health and productivity of interdependent communities of plants, animals and people" (El-Hage Scialabba 2007).

nitrogen input), less N_2O and CH_4 from biomass waste burning (as burning is avoided), and requires less energy, mainly due to zero chemical fertilizer use.
Its synergies between mitigation and adaptation also exert a positive influence. This in partly due to increase in soil quality, which reduce the vulnerability to drought periods, extreme precipitation events and water logging. Additionally, the high diversity of crops and farming activities in organic agriculture, together with its lower input costs, reduce economic risks.

Sustainable agriculture practices that preserve soil fertility and maintain or increase organic matter – such as crop rotation, composting, green manures and cover crops – can reduce the negative effects of drought while increasing productivity (Niggli et al. 2009). In particular, the water holding capacity of soil is enhanced by practices that build organic matter, helping farmers withstand drought (Altieri and Koohafkan 2008; Borron 2006). Conversely, organic matter also enhances water capture in soils, significantly reducing the risk of floods (ITC and FiBL 2007). Practices such as crop residue retention, mulching, and agroforestry conserve soil moisture and protect crops against microclimate extremes. In addition, water-harvesting practices allow farmers to rely on stored water during droughts, or to increase water availability. Diverse agroecosystems can also adapt to new pests or increased pest numbers (Ensor 2009).

Many of the above practices are inherent in ecological agriculture and easily implemented and play a primordial role in climate change mitigation. They include:- crop rotations and improved farming system design, improved cropland management, improved nutrient and manure management, improved grazing-land and livestock management, maintaining fertile soils and restoration of degraded land, improved water and rice management, fertilizer management, land use change and agroforestry (Bellarby et al. 2008). These ecological agricultural measures for mitigating GHG emissions and adaptation potentials to climate change have been place on table 9. Most of the practices are self-sufficient in nitrogen due to recycling of manures from livestock and crop residues via composting, as well as planting of leguminous crops (Ensor 2009; ITC and FiBL 2007). Moreover, practices rooted in ecological agriculture, such as introducing perennial crops to store carbon below ground and planting temporary vegetative cover between successive crops to reduce N_2O emissions by extracting unused nitrogen also mitigate climate change (Ensor 2009).

Table 9. List of ecological agricultural measures for mitigating GHG emissions and adaptation potentials to climate change.

Measure	Examples	Mitigative	Adaptation
Crop Management	Agroforestry	+++	+
	Water management	+++	++++
	Tillage management	+++	++
	Nutrient management	+++	++
	Residue management	+++	++
Livestock management	Improved feeding practices	++++	
	Specific agents and dietary additives	++	
Manure management	Composting	++ +	++
	More efficient use as nutrient source	++	
	Improved storage and handling	++	
Restoration of degraded lands	Organic amendments	+++	+
	Nutrients amendments	+++	
	Maintaining soil fertility	+++	+
Grazing land management	Grazing intensity	+++	+
Pasture management	Fire management	+++	+
	Nutrient management	+++	+
	Cover crops planted	+++	++
	Increased productivity	++	+
Bioenergy			
	Energy crops	+++	++
	Bioenergy use in commercial agriculture	+++	+
	Residues	+++	++
++ denotes	**Positive Mitigation of CO_2, CH_4, N_2O Positive adaptation potentials**		

(Source: Adapted from Smith et al. 2008)

4.10 Inter-relationships between adaptation and mitigation

Although adaptation and mitigation has been rather unconnected to date, it is clear that both the responses are equally important and can help reduce the risks of climate change to natural and human systems. The table below, adapted from Swart and Rees (2007), provides a summary of the definitions of climate change mitigation and adaptation, and some of their key differences and similarities. For example, adaptation tends to be more focused on dealing with the effects of change, is designed to avoid local damages over shorter time frames and directly benefits the communities that implement actions. This is different than mitigation, which is focused on the primary causes of climate change, is aimed toward avoiding long term global changes and provides no direct benefits to those who implement actions. There are exceptions to these rules, particularly with strategies such as local agriculture, which address both mechanisms simultaneously. Similarities include the fact that both mechanisms are aimed at reducing risks and limited by societal abilities to change.

Table 10. Definition, differences and similarities between adaptation and mitigation

Definition		**Adaptation**	**Mitigation**
		Adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities	Anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases
Differences	**Issues**	**Dominant Focus**	**Dominant Focus**
	Cause/ effects	Primarily addresses consequences	Primarily addresses causes
	Spatial Scale	Main objective avoiding local damage	Main objective avoiding global changes
	Key sectors	Mainly agriculture, urban planning , water and health	Mainly energy, transport, building and industry
	Time scale	Short-term benefit from reducing vulnerability	Long term benefits from avoided climate change
	Beneficiaries	Mainly benefits those who implement it (egoistic)	Mainly benefits others (altruistic)
	Incentives	Often incentives not needed	Usually incentives needed
Similarities	**Goal**	Aiming at reduction of climate risks	
	Benefits	Has ancillary benefits that may be as important as climate-related benefits	
	Drivers	Driven by availability/penetration of new technology and ability to change	

(Source: Adapted from Swart and Rees 2007)

5.0 Methodological framework of research

Different researches have gotten different strengths. It is therefore very important in combining multiple methods in order to produce a more meaningful and comprehensive information than each individual method would in isolation. (Morgan 2006; Denzin and Lincoln 2005). Combination of methods and the incorporation of results of multiple source of evidence add validity to a research, given the inevitable strength and short-comings associated with single methods studies (Jick 1979).

The aim of this research methodological implementation framework is to present the two different approaches used in the vulnerability assessment of subsistence farmer to climate change in the Sudano-Sahel of Cameroon. The approaches addressed here work hand in glove with methodological framework designed in the introductory chapter of this work already illustrated in figures 1 and 2, followed by detailed explanations.

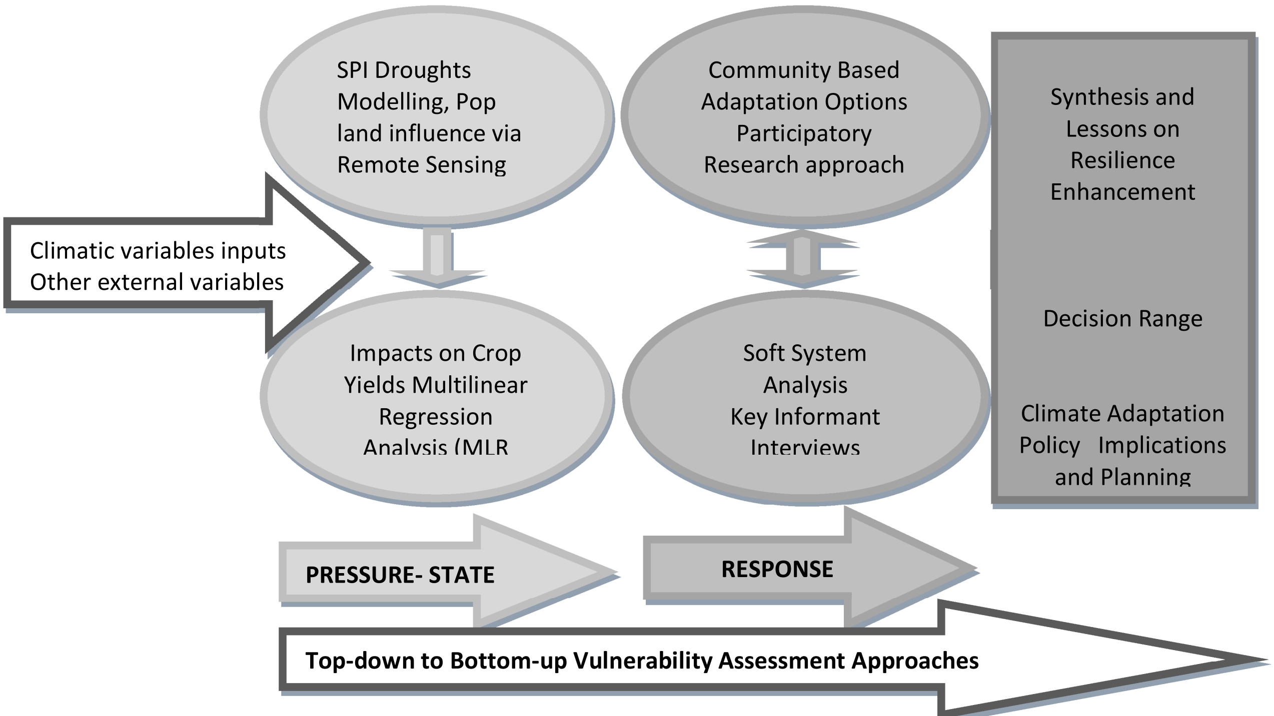


Figure 28. Analytical framework showing the approaches used in analyzing climatic impacts and other external variables on subsistent crops- options for adaptation from the various methods.

As with most terminology, there is a variety of interpretation of the top-down and the bottom-up methodologies. Both methodologies have been used in impact and vulnerability assessment carried out over the past 2 decades. Roughly, methodologies can be distinguished in the sense that the former is carried out from the mitigative perspective while the latter is done from the adaptive perspective (Dessai and Hulme 2004). Similar distinctions have been made by other others, such as “biophysical” versus “social vulnerability” assessments (Brooks 2003), first “generation” versus “second generation” assessments (Burton et al. 2002), “end-point” versus “starting point” assessments (Kelly and Adger, 2000).

Both paradigms have their strength and weaknesses in that indicators that emerge from the top-down approach are generally collected rigorously, scrutinized by experts and assessed using statistical tools. This process exposes trends (both between regions and over time) that might be missed by more casual observations. Reed et al. (2006) clearly indicates the inability of the approach in engaging local communities. Communities feel that their perspectives are not taken into consideration. Brown and Harris (2005) describe challenges to the top down approach including lack of communication and discontent that impeded cooperation between citizens and planning authorities. The bottom-up approach on the other hand developed through participatory techniques alone may not have the capacity for reliability and accuracy due to an iota of biasness (Kabat et al.2004).

5.1 Data base

5.1.1 Crop production data

Secondary crop data was used in this study. Historical crop statistics for the yield and harvested area data of millet and sorghum were obtained from the Food and Agricultural Organization (FAO) Agristat and from the National Institute of Statistics (NIS) of the Ministry of Agriculture and Rural Development, Cameroon. Times series for these crop yield and harvested areas was created.

5.1.2 Climatic data

The dataset includes temperature and precipitation data measured in degrees Celsius and millimeters respectively. The temperature data are measurements of minimum and maximum daily temperature and the precipitation data are measurements of 24-hour precipitation. Daily observed values of maximum and minimum temperatures, and rainfall were obtained from the University Corporation for Atmospheric Research (UCAR) (http://dss.ucar.edu/datasets) for the Sudano Sahelian region of Cameroon. The UCAR holds global datasets of station climatological normal and monthly time series of precipitation and mean, maximum and minimum temperature. For each region, the data from one of the major weather stations was chosen as representative of the climate of that region. See table below of weather station with their respective coordinates and altitudes in the Sudano-Sahel of Cameroon for the period of study between 1961- 2006.

Table 11. Weather stations data used with their respective coordinates

Region	**Station name**	**Latitude**	**Longitude**	**Altitude** (above sea level)
Far North	(Maroua-Salak	10.27N	14.13E	421m
North	(Garoua)	9.30N	13.40E	166m
Adamawa	(Ngaoundere)	7.31N	13.58E	1205m

The data is zipped in yearly files. Each file contains daily format from day 1 (January 1) to Day 365 or depending if it is a leap year or not (December 31). The data sets are in 3 columns. Column 1 was for the daily rainfall in millimeters (mm), column 2- the maximum temperature in degree Celsius (^{0}C) and column 3 for the minimum temperature also in degree Celsius (^{0}C). The choice of using the observed weather station data was based on the findings of Tingem et al. (2008). Who tested the weather generator ClimGen (version 4.1.05; http://www.bsyse.wsu.edu/climgen) for Cameroon (Tingem et al. 2008) and found to perform well in simulating the range of precipitation and temperature values at all sites. Hence the observed values of maximum and minimum temperatures, and rainfall readings were used for the study and time series was created.

5.1.3 Remote sensing data

Analyzed images for this study were obtained from the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) imageries freely downloaded from the website of the United States Geological Survey (USGS) (http://www.usgs.gov.). Details of image type, source, date of acquisition and date of modification are showed on the table 12.

Table 12. Remote sensing data

Data Type	Name and Source	Date of acquisition	Date of Modification
Landsat Image	Thematic mapper (TM) United States Geological Survey (USGS)	1987-1990	2005
Landsat Image	EnhanceThematic Mapper(ETM+) United States Geological Survey (USGS)	1999-2000	2009

5.2 Data quality control and homogenization

One of the most important steps in treating daily data is to make a quality control and look for inhomogeneities in the data sets. An inhomogeneity in a time series is defined as any changes in this time series that is not due to change in weather or climate (Mokssit 2003). As such it must be ensured that the data quality involved must be accurately and consistently registered by the same method, with the same instrumentation, same time of the day and place and in the same environment.

Karl and Williams (1987); and Peterson et al. (1998) pointed out that some of the causes that usually lead to such inhomogeneities include: - changes in instruments, changes in processing, changes in the environment around the shelter, changes in observing practices and changes in stations´ locations.

Houghton et al. (1992) however elaborated that long term variations and trends must be interpreted very cautiously. An accurate long-term climate analysis requires a good quality and homogeneous data, thus inhomogeneous must be detected and inhomogeneous series be excluded and adjusted.

There exist a plethora of works pertaining to the statistical testing in the detection of inhomogeneities. Alexanderson (1986) depends on metadata when the station history is poorly documented or totally missing.

For the purpose of this study, quality control procedures were aimed at identifying errors in data processing, detection and removal of errors in data, including human, instrumental, technological as well as environmental errors. The observed data were controlled using the ClimDex Version 1.3 software. It runs under Excel and was developed by Byron Gleason from NCDC/NOAA, USA. (http://cccma.seos.uvic.ca/ETCCDMI/software.shtml). No licensing is required. The software has in-built quality control and homogeneity test procedures and it enables the analysis of monthly data using some basic approaches (see Annex 2).

For quality control, the first step in the analysis process consists of the application of routine quality control procedures to a user's station data. The quality control checks performed are: At the first stage, obviously wrong temperature and precipitation data, such as negative rainfall (precipitation) or Rainfall less than 0.0 mm (PRCP < 0.0 mm) as well as Minimum Temperature greater than Maximum Temperature (Tmin>Tmax), were removed. The quality control procedure within ClimDex is not meant to be comprehensive but rather to assist a user in identifying common gross errors that may exist within daily station data (Annex 2).

After performing the quality control, ClimDex simply provides the user with a time series of annual mean (temperature) and accumulated values (precipitation). These time series can then be examined in conjunction with any existing metadata to identify potential inhomogeneities. The second step involves the user defining a "window" size in years. This window size is then split into two adjacent periods and then the difference between the two mean values are tested for any differences from 0 (e.g. two-sided t-test).

5.3 Top-down approach

The top-down methodologies have their roots in the field of climate change and climate impact assessment. The focus lies on the biophysical aspects of vulnerability. Generally, methodologies consist in the development of climate scenarios, which are fed into models of biophysical systems followed by a socioeconomic impact and adaptation assessment. They emphasize on the physical outcomes of climate change on crop yields, tree growth and plant growth etc. Focuses on the sensitivity of the physical environment to shocks and stressors and is often associated with traditional approaches to hazards (Dow 1992).

In this study, due to the over dependency of subsistence farmers on rain-fed agriculture, drought has been identified as the indicator of the pressure on the subsistence crops under study (millet and sorghum). In order to investigate this, the drought was taken as pressure indicator on the on crop productivity. The Standardized Precipitation Index (SPI) by (McKee et al. 1993) was used in the quantification of agricultural droughts occurrence, and the frequencies and intensities. Only the time series mean monthly rainfall 1960 to 2006 for the entire region was computed. Other variables such as temperature, evaporation and humidity were not taken into account.

Statistical tools were used in the assessing the state indicators via multiple regression models, with time series yield anomalies as the predictand and anomalies in minimum temperature, maximum temperature and rainfall for the crop growing season from May –August acting as the predictor variables. The Pearson Product Moment Correlation Coefficient was also used in exploring individual climatic variables relationships with yields for the entire growing period in order to identify those variables that influenced a significant portion of the observed yield variance.

5.3.1 Overview of SPI

Standard Precipitation Index is a state-of-the-art method for assessing climatic variability and was developed by McKee et al. (1993, 1995). The Standardized Precipitation Index (SPI) is a tool which was developed primarily for defining and monitoring drought. It allows an analyst to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. It can also be used to determine periods of anomalously wet events.

It is based on statistical techniques, which can quantify the degree of wetness by comparing three, six, 12 or 24- monthly rainfall totals with the historical rainfall period over the history. The SPI is based on rainfall only and works under the premise of the probability of an observed precipitation deficit occurring over a given prior time period. For example, a six monthly SPI for August 2006 will compare the March 2006 to August 2006 rainfall totals with historic totals for the March to August period.

The index is based entirely on monthly precipitation accumulations and its values can be compared across different climatic and geographic regions. These characteristics of the SPI have contributed to its popularity for application towards drought and water resource monitoring.

The SPI requires different interpretations according to its time scale and could be used in range of meteorological, agricultural, and hydrological applications. For example, the 1-month SPI reflects short-term conditions, and its application can be related closely to soil moisture; the 3-month SPI provides a seasonal estimation of precipitation; the 6- and 9-month SPI indicates medium term trends in precipitation patterns; and the 12-month SPI reflects the long-term precipitation patterns, usually tied to stream flows, reservoir levels, and even groundwater levels (NDMC 2007).

5.3.2 Method of SPI

Precipitation is the primary factor controlling the formation and persistence of drought conditions. Oladipio (1985) outlined that indices based solely on precipitation data perform well when compared with more complex hydrological indices. However, SPI is designed in such a way that it can detect drought over different periods at multiple time scales.

Conceptually, SPI is the number of standard deviations by which the precipitation values recorded for a particular location would differ from the mean over certain periods. In statistical terms, the SPI is equivalent to the Z-score (Giddingset al. 2005).

$$\text{Z-score} = \times - \frac{\mu}{\delta} \tag{1}$$

Z - score = (X-mean/standard deviation); where Z-score expresses the X score's distance from the mean (μ) in standard deviation (δ) units. Mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. The historic rainfall data of the station is fitted to a gamma distribution, as the gamma distribution has been found to fit the precipitation distribution quite well. This is done through a process of maximum likelihood estimation of the gamma distribution parameters, α andβ. In simple terms, the process described above allows the rainfall distribution at the station to be effectively represented by a mathematical cumulative probability function. Therefore, based on the historic rainfall data, an analyst can then tell what is the probability of the rainfall being less than or equal to a certain amount.

Thus, the probability of rainfall being less than or equal to the average rainfall for that area will be about 0.5, while the probability of rainfall being less than or equal to an amount much smaller than the average will be also be lower (0.2, 0.1, 0.01 etc, depending on the amount). Therefore if a particular rainfall event gives a low probability on the cumulative probability function, then this is indicative of a likely drought event. Alternatively, a rainfall event which gives a high probability on the cumulative probability function is an anomalously wet event.

5.3.3 Calculation of the SPI

This section clearly outlines the main mathematical steps required in the calculation of the Standardized precipitation Index. The SPI calculation for a specific time scale and location requires a long term monthly precipitation record with at least 30 years or more of data. Monthly precipitation time series are modeled using different statistical distributions. The first is the gamma distribution, whose probability density function is defined as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{for } x > 0 \qquad (2)$$

whereα> 0 is a shape parameter, β> 0 is a scale parameter, and x > 0 is the amount of precipitation. $\Gamma(\alpha)$is the gamma function, which is defined as

$$\Gamma(\alpha) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \frac{n! n^{y-1}}{y+v} \equiv \int_0^{\infty} y^{\alpha-1} e^{-y} dy \qquad (3)$$

Fitting the distribution to the data requires $\alpha$and $\beta$to be estimated. Edwards & McKee (1997) suggest estimating these parameters using the approximation of Thom (1958) for maximum likelihood as follows

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (4)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \quad (5)$$

Where for n observations

$$A=\ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (6)$$

This approach is refined using an iterative procedure suggested by Wilks (1995)

$$\begin{bmatrix} \alpha* \\ \beta* \end{bmatrix} = \begin{bmatrix} \hat{\alpha} \\ \hat{\beta} \end{bmatrix} - \begin{bmatrix} \frac{\partial^2 L}{\partial \hat{\alpha}^2} & \frac{\partial^2 L}{\partial \hat{\alpha} \partial \hat{\beta}} \\ \frac{\partial^2 L}{\partial \hat{\alpha} \partial \hat{\beta}} & \frac{\partial^2 L}{\partial \hat{\beta}^2} \end{bmatrix}^{-1} \begin{bmatrix} \frac{\partial L}{\partial \hat{\alpha}} \\ \frac{\partial L}{\partial \hat{\beta}} \end{bmatrix}$$

$$= \begin{bmatrix} \hat{\alpha} \\ \hat{\beta} \end{bmatrix} - \begin{bmatrix} -n\Gamma''(\hat{\alpha}) & \frac{-n}{\hat{\beta}} \\ \frac{-n}{\hat{\beta}} & \frac{n\hat{\alpha}}{\hat{\beta}^2} - \frac{2\Sigma x}{\hat{\beta}^3} \end{bmatrix}^{-1} \begin{bmatrix} \Sigma \ln(x) - n\ln(\hat{\beta}) - n\Gamma'(\hat{\alpha}) \\ \frac{\Sigma x}{\hat{\beta}^2} - \frac{n\hat{\alpha}}{\hat{\beta}} \end{bmatrix} \quad (7)$$

Where $\alpha *$ and $\beta *$ are generally better estimates of α and βthan $\hat{\alpha}$ and $\hat{\beta}$.The process is repeated until the algorithm converges. If no convergence is detected Thom´s estimate of α andβ are used.

Integrating the probability density function with respect to x and inserting the estimates ofα andβ yields an expression for the cumulative probability G(x) of an observed amount of precipitation occurring for a given month and time scale:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}} e^{-x/\hat{\beta}}\, dx \quad (8)$$

Substituting t for$x/ß$reduces Equation (6) to

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1}\, e^{-1} dt \quad (9)$$

Which is the incomplete gamma function. Values of the incomplete gamma function are computed using algorithm taken from Press et al. (1996). Since the gamma distribution is undefined for $(x) = 0$ and $for\ q = P(x = 0) > 0$ where $P(x = 0)$ is the probability of zero precipitation, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \quad (10)$$

H(x) is then transformed into a normal variation Z by means of the following approximation provided by Abramowitz and Stegun (1965):

$$Z = SPI = -\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right) \quad for\ 0 < H(x) \le 0.5 \quad (11)$$

$$Z = SPI = +\left(t - \frac{c_0+c_1t+c_2t^2}{1+d_1t+d_2t^2+d_3t^3}\right) \quad for\ 0.5 < H(x) \le 1 \quad (12)$$

Hence, SPI represents a Z-Score variable and is normalized.

5.3.4 SPI classification

The SPI is a dimensionless index where negative values indicate less than median precipitation (droughts), but positive values show greater than median precipitation (wet conditions). McKee et al. (1993) used the classification system shown on table 2 below. In the SPI values table to define drought intensities resulting from the SPI. McKee et al. (1993) also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude. McKee et al. (1993) present a drought classification scheme and corresponding event probabilities (Table 13).

Table 13. Drought classification by SPI value and corresponding event probabilities

SPI Value	Category	Probability %
2.00 or more	Extremely wet	2.3
1.5 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to -0.99	Mild drought	34.1
-1.00 to -1.49	Moderate drought	9.2
-1.50 to -1.99	Severe drought	4.4
-2 or less	Extreme drought	2.3

Based on an analysis of stations across Colorado, McKee determined that the SPI have a percentage occurrence in mild drought of 24% of the time, and 9.2% moderate drought of the time. At a given location for an individual month, severe drought (-1.5 to -1.99) have an occurrence probability of 4.4%, whereas extreme droughts (SPI < −2) have an event probability of 2.3. This table also contains the corresponding probabilities of occurrence of each severity, these arising naturally from the normal probability density function.

5.3.5 The SPI Program Operation and Computation

The SPI program is a freeware that is relatively easy to operate. The program is ready compiled in C++ for PCs. It is made available by the National Drought Mitigation Center of the University of Nebraska- Lincoln USA and downloaded via http://www.drought.unl.edu/monitor/spi/program/spi_program.htm. The downloaded program file appears as SPI_SL_6.exe which could be saved and executed when a dialogue box pops on the screen is shown on Annex 3. An input file for a given station must follow a 3-collumn format: year, month, and monthly precipitation value. The precipitation total must not include decimals and in this study, the values were measured in millimeters. Sample input and output data file have been placed in annex 4a and 4b respectively). Output data files were named with a.dat (or txt or spi etc). It should be reiterated that one must have at least 30 consecutive years without missing monthly data and more than 60 years is recommended.

5.3.7 Comparing the SPI with other drought indices

Although there exist different drought indices such as the Palmer drought severity index (PDSI) and the moisture anomaly index (Z-index) (Palmer 1965), the aridity index (Gore and Sinha 2002) and Percent Normal, Deciles (Gibbs and Maher 1967). Drought indices, in general, enable the detection of the onset of drought events and enable their severity to be measured, thereby allowing an examination of the spatial and temporal characteristics of drought, and comparisons between different regions to be made. The majority of drought indices have a fixed time-scale. For example, the PDSI has a time-scale of about 9 months (Guttman 1999), which does not allow identification of droughts at shorter time scales, as in the case of agricultural drought. Among others, the Colorado Climate Center, the Western Regional Climate Center, and the National Drought Mitigation Center used the SPI to monitor current states of drought in the United States.

5.3.8 Merits of the SPI

1. The first and primary advantage is simplicity. The SPI is based solely on rainfall and requires only the computation of two parameters, compared with the 68 computational terms needed to describe the PDSI. By avoiding dependence on soil moisture conditions, the SPI can be used effectively in both summer and winter. The SPI is also not affected adversely by topography. It is less complex to use than other indices.

2. The SPI's second advantage is its variable time scale, which allows it to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications. This temporal versatility is also helpful for the analysis of drought dynamics, especially the determination of onset and cessation, which have always been difficult to track with other indices (Hayes et al.1999).

3. The third advantage comes from its standardization, which ensures that the frequencies of extreme events at any location and on any time scale are consistent

5.3.9 Demerits of the SPI

1. There is the assumption that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization. An associated problem is the quantity and reliability of the data used to fit the distribution. McKee et al. (1993) recommend using at least 30 years of high-quality data.

2. The second limitation of the SPI arises from the standardized nature of the index itself; namely that extreme droughts (or any other drought threshold) measured by the SPI, when considered over a long time period, will occur with the same frequency at all locations. Thus, the SPI is not capable of identifying regions that may be more 'drought prone' than others. (Llyod-Hughes et al. 2002)

3. A third problem may arise when applying the SPI at short time scales (1, 2, or 3 months) to regions of low seasonal precipitation. In these cases, misleadingly large positive or negative SPI values may result.

5.4 Remote sensing method and analysis

Spatio-temporal land use and land cover dynamics were studied using remote sensing techniques for the study area. The image data used in the study were Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (TM+). The TM data are one of the most frequently used data for environmental assessment and monitoring. The images acquired were between 1987 and 1990 from the United States Geological Survey (USGS 2012). The date of acquisition of the TM+ images on the other hand was for the year 2000 of which was lastly modified in 2009. The bands selected in generating false color composite images were 4, 3 and 2.

The data from Landsat imageries were then processed by ERDAS Imagine 9.1 software for spatio-temporal analysis of land use and land cover (Erdas 2006). Supervised digital image technique was employed and complemented with the field surveys that provided on-the-ground information about the land use types and land cover dynamics as a result of human and natural influences (Eastman 2009). Calculation of the of the percentage area of the resulting land use and land cover types each of the study area and subsequent result comparison was done. These helped in the identification of change in land use types particularly based on the different classes. Given the homogeneity of subsistence farming in the Sudano-Sahel of Cameroon, the Maroua study area was selected as a hotspot area for the Sudano-Sahel. This was aided by purposive sampling techniques used in the administered questionnaires surveys.

5.5 Multiple regression analysis of climatic variable impacts on subsistence crops

5.5.1 Description and purposes of the technique

Regression analysis is the statistical technique that identifies the relationship between two or more quantitative variables: a dependent variable, whose value is to be predicted, and an independent or explanatory variable (or variables), about which knowledge is available. The technique is used to find the equation that represents the relationship between the variables. Multiple regression provides an equation that predicts one variable from two or more independent variables, $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots. + \beta_kX_k + \varepsilon$ (13)

Where Y is the change that the program is mainly supposed to produce (e.g. subsistence crop yields). $X_{1\text{-}k}$ are independent variables likely to explain the change.
$\beta_{0\text{-}k}$ are constants, and ε is the error term.

5.5.2 Yield functions

In order to study the impact of recent climatic trends on millet and sorghum in Sudano Sahelian Cameroon, stepwise multiple regression analysis were developed using time series yield anomalies as the predictand. While anomalies in minimum temperature, maximum temperature and rainfall for the crop growing season from May –August acted as the predictor.

While assessment of climatic contributions to yield trends remains an important topic, interpretation of results using any individual technique is often imprecise (Lobells et al. 2006). Thus the model was run firstly with said climatic variables. Thereafter there was the inclusion of the harvested areas anomalies as the sole non climatic variable to witness which combination of factors accounted for the most variation in yields of the staple crops.

The following equation was then used for the regression analysis:

$Y = \beta_0 + \beta_1 T_{min} + \beta_2 T_{max} + \beta_3 Ha + \varepsilon$, where (14)

Y = Crop yields for Millet or Sorghum

T_{min}= Average minimum temperature during the growing period

T_{max}= Average maximum temperature during the growing period

Ha= Average crop harvested areas; $\beta_{0\text{-}k}$ are constants, and ε is the error term

The Pearson Product Moment Correlation Coefficient was also used in exploring individual climatic variables relationships with yields for the entire growing period in order to identify those variables that influenced a significant portion of the observed yield variance. The statistical software SPSS 17.0 was used at a 95% confidence interval level.

The advantage of this statistical base approach is that they intrinsically account for a wide range of mechanisms that can influence yields in a changing climate. It provides an excellent option because it allows one to investigate the individual input variables that are capable of influencing crop yields while maintaining all other variables constant. For this reason, this approach has been largely used to assess climate variability or climate change impacts in many regions of the world.

5.5.3 Model assumptions

The interpretation of most empirical statistical analyses is subject to certain assumptions and this study is no different. It is difficult to isolate the impacts of climate on crop production due to the confounding effects of technological improvements (new genotypes, crop husbandry, and cropping systems) or biophysical (soils, pest and diseases) or socioeconomic (population influence, extension and research, improved varieties, credits, land tenure, markets, credits) and management related that contribute to the increase in crop yields. Management changes from year to year, perhaps as a response to price expectations, may have occurred over this time period. To the degree that omitted variables are correlated with temperature and rainfall, the estimated effects of latter variables may be biased. It is important to note that some variables that may cause some yield changes have been omitted from the analysis due to lack of data.

Other shortcoming of this model is that it does not explicitly consider management changes or other factors such as carbon dioxide fertilization that may alter the effect of climate on yields. Inter-annual variations in incoming solar radiation, for example would likely impact growth but have not been explicitly considered here. Thus this study assumed a degree of uniformity across the entire Sudano Sahelian region in those factors other than climate that could influence crop yields. This degree of uniformity is simple the fact that one has no reason to believe that subsistence farmers in one portion of the study areas would have a decisive edge over others in obtaining (performing) better agricultural management practices.

5.6 Bottom-up approach

In the bottom-up methodologies, focus lies on the social aspects of vulnerability. Generally, methodologies consist in conducting case studies on the level of local communities; social conditions, institutions and the perception of vulnerability are hereby emphasized. Trends are rooted in an understanding of the local context and are derived by systematically understanding local perception of the environment and the society. The social vulnerability focuses on livelihood strategies and ways that people secure these in dynamic physical and socio-economic environments (Eriksen et al.2005).

Bottom-up approaches begin with the end user and their perspectives and therefore take more time initially. However results from bottom up approaches can be more lasting and acceptable to end-users and can help communities find agreement on adaptation issues to climatic variability and change. Bottom up indicators in this study were investigated using the Soft System Methodology (Checkland 1999).

5.6.1 Soft system methodology

Soft System Methodology (SSM) is essentially designed to shape interventions in the problematic situations encountered in management, organizational and policy contexts, where there are often no straightforward 'problems' or easy 'solutions.' Though informed by systems engineering approaches, it breaks with them by recognizing the central importance of perspective or world-view in social situations. It differs significantly from the 'systems science' approaches developed in the 1960s, and is more reflective of action research in its philosophy and approach.

5.6.2 The SSM process

Checkland's 7-stage model progresses from finding out about a situation to taking action to improve it.

During stages 1 and 2 the problem is still unstructured and expressed by the participants in a rich picture. Stages 3 and 4 involve systems thinking. Root definitions and conceptual models of possibly relevant systems are developed. The remaining stages are again set in the real world where action can take place. During stage 5 the ideal conceptual model is used to find similarities and differences with the perceived real world model. Stage 6 involves recommendations for culturally feasible changes and stage 7 requires the implementation of the changes agreed to during the previous stage. These 7 stages are part of the logic-based stream of inquiry and provide a functional analysis of the problem situation.

SSM is widely described as a seven-stage process, as follows:

Identifying the problematic situation that it is desired to
Researching the situation and building a 'rich picture'
Selecting perspectives and building 'root definitions'
Developing a conceptual model of the change system
Comparing the model with the real-world situation
Defining the changes to be implemented
Taking action

Figure 29. Seven-stage process of Soft System Methodological
Source: adapted from Checkland (1999).

Soft System Methodological (SSM) implementation was via a participatory research approach in investigated the sensitivity and vulnerability of subsistent farmers and explored the adaptation behavior and pattern perceived by local communities in the face of variable climatic conditions with key informant interviews and in-depth interviews via questionnaires being established to ensure that all stakeholders exposed to the problem was dealt with. These participatory approaches can help ´´identify and respond to the local, cultural, historical, socio-economic, geographical and political factors that influence the behavior and practices of the community´´ (Beazley and Ennew 2006).

5.7 Sampling strategy

Due to resource constrains during the field studies, it was practical to sample respondents for qualitative data capture purposively. Qualitative investigation involves a continuous process of data collection and conceptualization until a new data does not add to development theory. The sampling strategy used in the implementation of the above soft system methodology (SSM) was purposive sampling.

Purposive sampling is one which is selected by researcher subjectively and very useful where one needs to reach a targeted sample quickly as well as gaining an in-depth and context rich understanding of issues (Trochim 2006). Although with this type of sampling, one is more likely to get the opinions of the targeted population, subgroups are likely to overweight in the population that are more readily accessible, which may be potential source of error. This research utilized two sub-categories of purposive sampling: - expert sampling and snowball sampling.

5.7.1 Expert sampling

This involved the assembling of sample of persons with acknowledged and insight into the field or topic. This was done via Key Informant Interviews (KIF). Two key informant interviews each were first conducted from each of the 3 different regions of the Sudano-Sahel zone of Cameroon. The key informants were mainly Agricultural Extension Service workers from IRAD (Institut de Recherche Agricole pour le Développement). Key informant interviews aided in the selection of the neighborhoods where subsistence farming was the order of the day and provided evidence for the validity of the next purposive sub-sampling category (snowball sampling). Implying that respondents were selected based on the above premise and were also used in the establishing the reliability and consistency that allowed findings from the household questionnaires to be compared with. The interviews were then used to explore and conceptualize approaches by subsistence farmers to adaptive capacity, and its perceived utility for decision making.

5.7.2 Snowball sampling

This was the second process of purposive sampling used in this research. Snowball sampling involves the identification of someone who meets the criteria in the study. Snowballing sampling is especially useful when trying to reach population that is inaccessible or hard to find. This actually worked well with the household questionnaires whereby the subsistence farmers in the Sudano Sahel villages were the target population groups no more no less. Snowball sampling is capable of introducing an important type of error known as self-selection error, whereby the respondents themselves decide that they would like to take part in the survey. This error often makes it unlikely that the sample will accurately represent the broader population (Trochim 2006). In this research therefore, self-selection error was eliminated by conducting the sampling through the two steps process of expert sampling followed by snowball sampling.

5.8 Questionnaires

The household questionnaires involved semi-structured open ended, closed ended questionnaires conducted across villages in the 3 regions of the Sudano-Sahel with Mayo Tsanaga (Far north region), Mayo-rey (North) and Gbaya and Mbum (Adamawa) regions, being the most surveyed areas due to subsistent farmers' population pool. Those were the easily accessible villages chosen for the interviews. The questionnaires have been placed in annex 1. The Questionnaire was compiled in five thematic sections:

- Household information
- Agricultural dependency and crop types produced
- The state of knowledge of subsistent famers on climate change
- Currents adaptation practices
- Constraints and ways forward

It is worth mentioning that working with a female assistant was necessary because the Fulbe society is sex-segregated. Men and women spend their days in separable quarters of the compound and spend relatively little time together. Some areas where interviews were conducted were affected by Islamic renewals and a local translator was used.

5.9 Data analysis

A total of 300 questionnaires each was administered each region. In some questions, respondents were given the options of multiple responses. The study was conducted at a face-to-face level and a respondent rate of about 81% was obtained. Quantitative data were organized and facilitated for qualitative analysis. Analysis was based mainly on descriptive analysis and presentation. The statistical package (SPSS) 17.0 was used for analysis. Analysis of variance (ANOVA) was first used to check if there was significant difference between the mean responses to climate change perceptions, and adaptation strategies towards curbing the impacts at a 95 % confidence interval ratio in the 3 different region of the Sudano-Sahel.

5.10 Differences between top-down and bottom-up approach

Table 14. Contrast between a top-down versus bottom-up assessment of vulnerability of resource to climate variability and change

APPROACH	SCENARIO	VULNERABILITY
Assumed dominant stress	Climate, recent greenhouse gas emissions to the atmosphere, ocean, temperature aerosols etc	Multiple Stresses: Climate (historical climate variability, land use and water use, altered disturbance regime invasive species, contaminants/pollutants, habitat loss etc
Usual timeframe of concern	Long term, double CO_2 30 to 100 years in the future	
Usual Scale of Concern	Global, sometimes regional. Local scale needs downscaling techniques. However, there is little evidence to suggest that present models provide realistic, accurate, or precise climate scenarios at local and regional scales	Local, regional, national and global scale
Major Parameter of Concern	Spatially averaged changes in mean temperatures and precipitation in fairly large grid cells with some regional scenarios for drought.	Potential extreme values in multiple parameters (temperature, precipitations, frost-free days) and additional focus on extreme events (floods, droughts fires, etc measures of uncertainty.
Major Limitations for developing coping strategies	Focus on single stress limits preparedness for other stresses. Results often show gradual ramping of climate changing limiting preparedness for extreme events. Results represent only a limited subset of all likely future outcomes-usually unidirectional trends. Results are accepted by many scientists, the media, and the public as actual "predictions". Lost in the translation of results that all models of the distant future have unstated (presently unknowable) levels of certainty or probability	Approach requires detailed data on multiple stresses and their interactions at local, regional, national and global scales – and many areas lack adequate information Emphasis on short- term issues many limit preparedness for abrupt "threshold" changes in climate sometime in the short or long term. Requires preparedness for a far greater variation of possible futures, including abrupt changes in direction – this is probably more realistic, yet difficult

Source: (from Kabat et al. 2004)

6.0 Results and Discussion

This section presents the results and detailed discussion of the research findings. It starts off with drought analysis of the standardized precipitation index, the remote sensing data analysis that is then closely followed by results of the regression analysis and ends up with discussion of the questionnaire outputs arranged in a sequential order.

6.1 Analysis of climatic variability and change in the study area

6.1.1 Results of drought index analysis

The drought vulnerability in the three study areas of the Sudano-Sahel was assessed by reconstructing historical occurrence of droughts at a 9-months' time scale, employing the SPI approach, starting from March and ending in November, corresponding to the past nine months of observed precipitation totals respectively. This time scale is a reflection of the agricultural period from planting to harvesting in the region of study including the likelihood where an iota of rainfall could be observed. Shown in figures 30-32 are 9-months Standardized Precipitation Index trends and patterns for weather stations reading for Maroua, Garoua, and Ngaoundere. The appearance of drought is happening every time when SPI is negative and its intensity comes to -1.0 or lower. The positive values in the SPI indicate greater than mean precipitation while negative values indicate less than mean precipitation.

In figures 30-32, patterns of SPI values for Maroua, Garoua, and Ngaoundere stations are quite similar but the magnitude, intensity and occurrence for year of drought are different for the different stations and are also difficult to differentiate among the SPI time series. It is obvious that drought phenomenon will create more vulnerable environment for the subsistence farming sector. While Ngaoundere experienced less extreme drought, Maroua and Garoua were more prone to random droughty conditions as several moderate and severe droughts were detected between the covered periods of 1961-2006. Based on the similar patterns shown in the curves, major events have been observed in the years of 1966, 1970, 1972-1973, 1987-1990, 1997, 2000, and 2006.

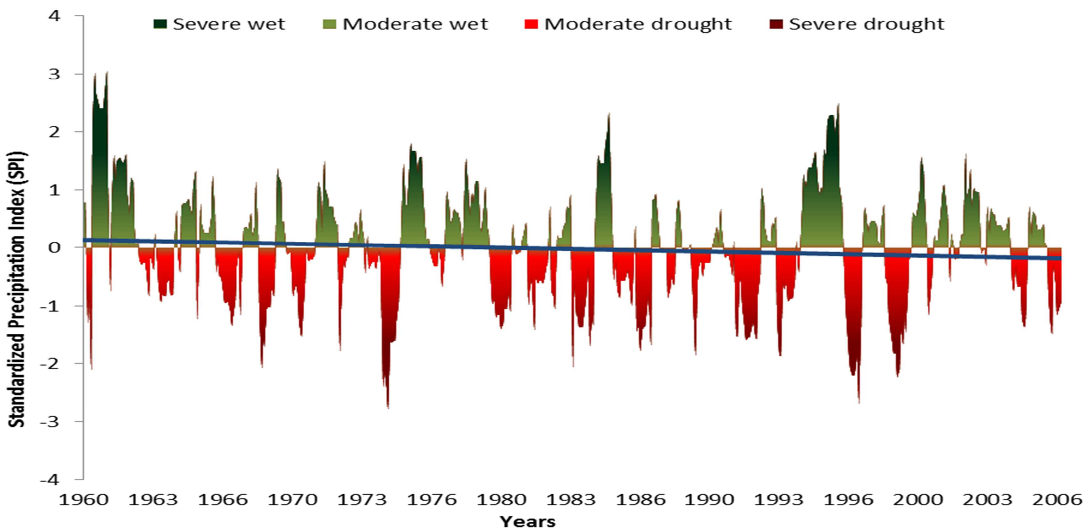


Figure 30. 9 Months SPI for Maroua from 1960-2006 with trendline.

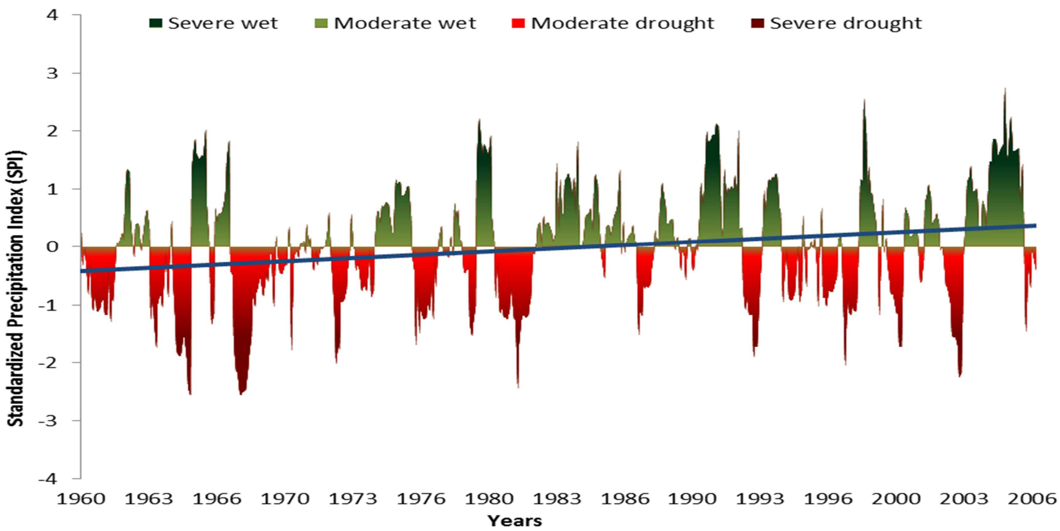


Figure 31. 9 Months SPI for Garoua from 1960-2006 with trendline.

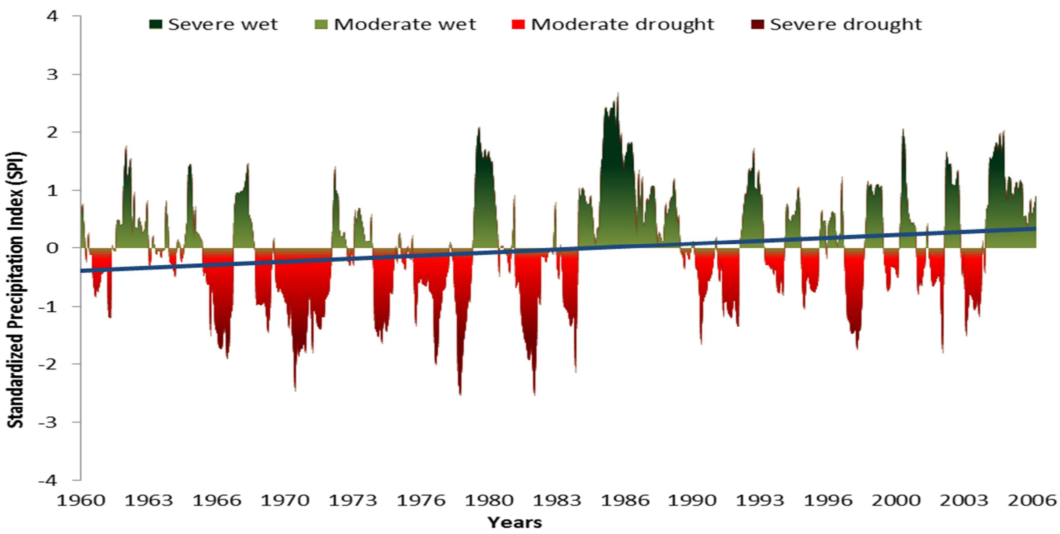


Figure 32. 9 Months SPI for Ngaoundere from 1960-2006 with trendline.

SPI aims at identifying and delineating drought characteristics in giving an indication of drought characteristics such as the severity and the extent of it. The probability of occurrence of dry or wet according to each category is shown on table 15. The differences between the frequencies of occurrence of the SPI range for the three regions of the Sudano Sahel of Cameroon are small. Extremely drought periods (SPI values of -2 or less) with potentially extreme drought occurred in about 3 % of the years. Severe drought periods (SPI values between -1.5 to -1.99) occurred approximately 5 to 6 % of the years. Results of the SPI in 1969, 1987, 1988, 1998, 2005 indicate years of total dryness. On the other hand, between 8 to 10 % accounted for the severe wet period (SPI value of +1.5 to +1.99). Extremely humid periods with potentially severe flooding occurrence were between 6 to 8.5 %. Results of the SPI in 1984 and the early years of 2000 were indicating wet periods.

Table 15. Standardized Precipitation Indices and categories combined with the percentage of occurrence over the period of 1961 to 2006 in the Sudano Sahelian region of Cameroon

			Percentage Frequency of Occurrences		
Drought Category	**Colour Range**	**SPI Range**	**Maroua**	**Garoua**	**Ngoundere**
Extreme Drought		**-2.0 or Less**	2.4	2.7	1.5
Severe Drought		**-1.5 to -1.99**	4.9	4.9	5.6
Moderate Drought		**-1.0 to -1.49**	10.3	10	10.9
Mild Drought		**-0.99 to 0**	34.2	31.5	35.1
Normal		**+ 0.01 to + 1.49**	34.6	33.5	29.4
Severe Wet		**+1.5 to +1.99**	7.8	8.9	10
Extreme Wet		**+2.0 or more**	5.8	8.5	7.6

6.1.2 State of knowledge of farmers on climate change

For subsistence farmers to adapt to recent climatic variability and changes, they must from the onset be able to perceive that changes are actually taking place. Perception parameters assessed at household and farm levels indicates that farmers have a flagrant memory of extreme climatic conditions and other significant events leading to disturbances in crop productivity. Increase in temperature and the decline in rainfall are the predominant perceptions in the area of study.

6.1.2.1 Subsistence farmers' perception on temperature changes

About 84% of the subsistent farmers interviewed perceived long-term changes in temperature in the Sudano- Sahelian zone of Cameroon have increased. Only 4 percent noticed a decrease and 12 percent on the contrary have observed no changes. It is worth mentioning that the interviews with the extension service workers generally corroborate the household and farm questionnaire results as the respondents were very concerned with the increasing dry days and high temperatures. Percentage respondents that noticed no decrease in temperature was 1%, 3% and 8% for Maroua, Garoua and Ngaoundere respectively. See histograms below.

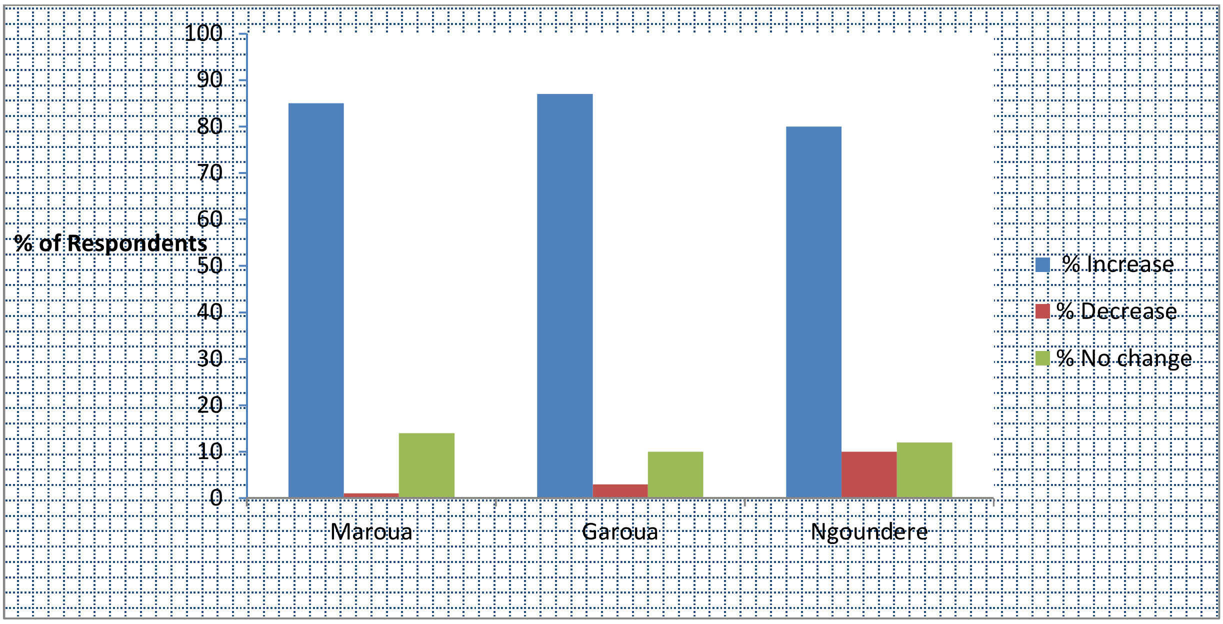


Figure 33. Farmers' perception of changes in temperature in the Sudano-Sahel of Cameroon

6.1.2.2 Subsistence farmers' perception on rainfall changes

In total, 91% responding that the amounts of rainfall have reduced considerably. There have been observed changes in the rainfall pattern over the past decades. Less than 2% observed no rainfall changes. In Maroua for instance, a 0% change in the rainfall pattern was perceived by the farmers while the percentage respondents in Garoua and Ngaoundere that saw slight changes in the rainfall pattern was 1 and 3 percent respectively (figure 34). Similarly, the interviews with the extension service workers generally corroborate the household and farm questionnaire results as the respondents were very concerned with the lateness of the coming of the rains and the decrease in its intensity.

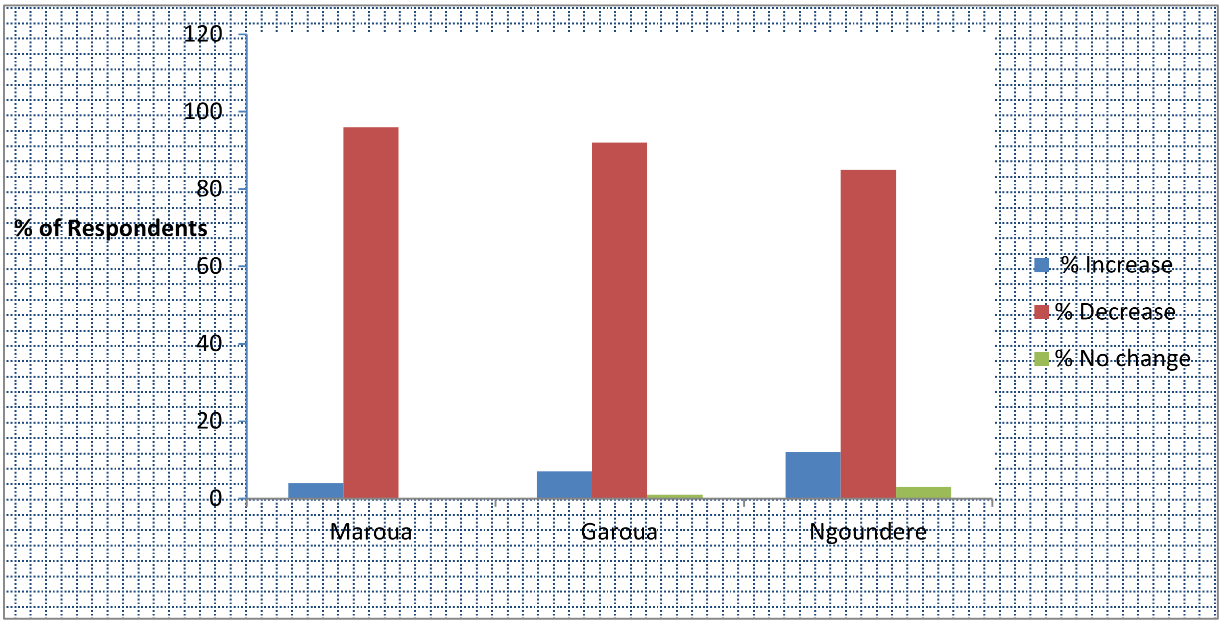


Figure 34. Farmer's perception of changes in rainfall in the Sudano-Sahel of Cameroon

6.2 Discussion

The results indicated a variation in the climate of the Sudano-Sahelian region of Cameroon with very critical changes particularly during the growing seasons from May-August for the study period of 1961-2006. This could be accounted for by the geographical location of the country; having a dry northern region encompassing the Sudano-Sahel, and a well-watered southern equatorial region. Kenga et al. (2005) observed variations in the growing seasons of up to less than 120 days in this region. These results on variability in the climate also corroborate with the outcomes of the interviews with the local farming pertaining to their perceptions on climatic variability and change in the Sudano-Sahel, whereby the majority of respondents perceived increasing temperatures and decreasing rainfall patterns. Maddison (2006) reported similar findings where a significant number of farmers in eleven African countries believed that the temperatures had increased while the rainfall intensity had dropped. Although in Maddison´s findings, Cameroon was an exception in the fact that most of those questioned believed that there had been no changes in temperature than that there had been an increase. The change in the agro-ecological zone from the Sudano-Sahel to the savannah type as one cruise southwards could be the reason for these changes. It should be noted that this research was based in the Sudano-Sahel and not in the whole Cameroon as he did. However, other batteries of scholars have reported similar findings. These include the works of (Mertz et al. 2009; Thomas et al. 2007; Mary and Majule 2010; Gbetibouo 2009; Ishaya and Abaje 2008).

Droughts have a very pronounced impact because of the relative importance in the agricultural sector. Drought incidences have been prevalent in the Sudano Sahel based on the results of the Standardized Precipitation Index (SPI). It does not take severe drought to affect crop yields. Even moderate lack of available water can drastically reduce crop yields. These types of droughty periods usually cause damage to rain-fed agriculture and the consequences are usually dramatic in that they render the agricultural soils very unstable, prone to crusting and soil hard-setting (Valetin 1995) thereby making crop production very difficult. The possibilities of increase in desertification are also increased. The SPI droughts result analyzed were in accordance with the response of the subsistence farmers that climate has been changing with many incidences of dry periods. In trying to understand why people may declare one year as a drought, it is important to recognize their needs in terms of rainfall – their dependency on rain-fed agriculture. This falls within the premise that people needs are used as kind of benchmark when they compare individual years. Drought per se is a very diffuse concept and the threshold identified for defining it is somewhat arbitrary (Agnew and Chappell, 1999). The mid 1960s, mid 80s, early 90s, were droughty years characterized by severe famine in the Sudano-Sahelian. This coincide with the findings of (Tingem et al. 2008; Molua 2008) who both referred to this periods as years of the Sahelian drought.

Plethora of hypotheses have been put forward as to the causes of the Sahelian drought, with Charney (1975) who attributed it to the systematic and irreversible land degradation and desertification caused by the farmers and pastoralists of the region. Nicholson (2001) on the other hand offers one of the most convincing hypotheses today in arguing out that during the second half of the 20th century the warming of the south Atlantic and the Indian Ocean in contrast to the cooling of the north Atlantic reduced the land-ocean temperature differential. This in turn caused the monsoon to weaken. Rainfall in the Sahel is characterized by the great variations from year to year and from decade to decade, governed by the motions of the Inter-tropical Convergence Zone (ITCZ). The ITCZ and its associated deep convection migrated southwards thus depriving the Sahel of rainfall. The last hypothesis is attributed to the El Niño effect that also might have been an influence and a positive feedback loop involving the Sahelian vegetation. As the monsoon weakens, so less vegetation grows, the surface albedo (reflectivity) increases, reflecting back the solar radiation so further weakening the monsoon. This may well explain the recent Sahelian drought but it leaves open what will happen in the future (Brooks 2004; Zaal and Dietz, 2004).Additionally, rainfall needs similarities amongst farmers in the three regions of study are indications that subsistence farmers, be it pastoralist, or normal farmers generally hope for early start of the rainy season for pasture growth and water for livestock. Animals become weaker and cranky during the dry seasons while the soils stay stronger and harder concomitantly having impacts on their livelihoods.

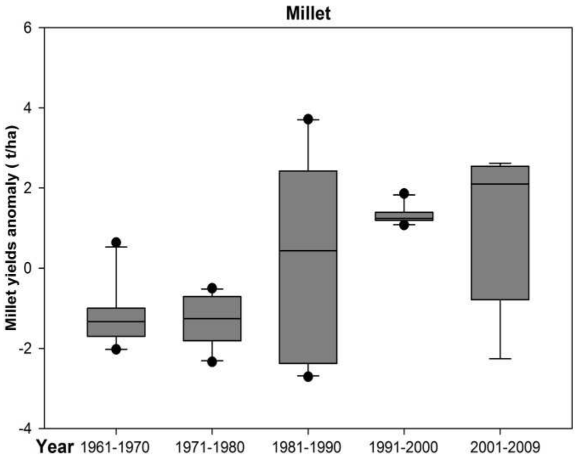
The trend lines for Garoua and Ngaoundere regions show an increase into the wetter regions based on the SPI model, with Maroua being in the region of moderate drought. This could be accounted for, based on the country's location in having a dry north and a wetter equatorial south as one cruises downwards. However, recent studies have shown that the increase in the Sahelian rainfall has been triggered by an increase in surface temperatures in the Sahara desert. Haarma et al. (2005) argue that the Sahara heats up faster than the Atlantic Ocean. This causes air with more moisture to move in from the Atlantic and thus more rains (wetter conditions) over the Sahel. Higher temperatures over the Sahara would cause 1-2 mm of extra daily rainfall in the Sahel during the months of July to September by 2080, which would be 25-50 percent more rainfall that fell in the drought ridden region during the 1980s (Brahic 2005).

To substantiate to the reasons to account for the presence of wet conditions, could be the possibilities of a reverse effect in the movements of the Inter-tropical Convergence Zone (ITCZ) already described. It is argued that historically, the southern Atlantic Ocean was warmer than the northern Atlantic Ocean. This drew rain-bearing monsoon winds away from the Sahel, contributing to the very dry conditions there. From the 1990s, however, the situation changed and the northern Atlantic Ocean became warmer than the southern Atlantic, partly because of higher levels of greenhouse gases in the atmosphere. As a consequence, there has been more rainfall in the Sahel (Kigotha 2005)

6.3 Changes in subsistence crop production

6.3.1 Trend analysis in subsistence crop production

There have been changes in both the yields and harvested areas for millet and sorghum in the Sudano-Sahelian region of Cameroon. Significant yield increases have been observed during the last 4 decades for both crops (Figures 35a &35 b) with respect to climatic variability. Millet yields since the 90s have increase from an average of 0.7 tons per hectare to about 1.0 tons per hectare. In contrast, significant dropping trends were observed for sorghum during the last decades. Nevertheless, below average yields were observed in the 1960s, 70s and 80 for all crops. Harvested areas allocated to each crop showed variability with respect to climate as well. Millet harvested areas increased to about 120,000 ha till the 80s and then dropped to about 50,000 ha (Figure 36a &36 b).



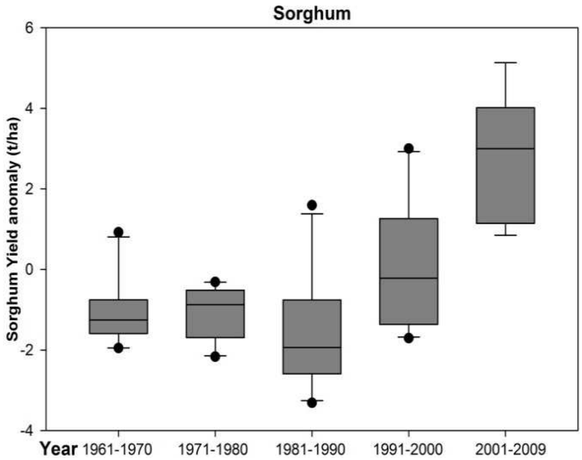


Figure 35(a & b). Showing decadal crops yield anomalies impact of climate trends (1961-2006). The negative values show loss in yields. Error bars show 95 % confidence interval.

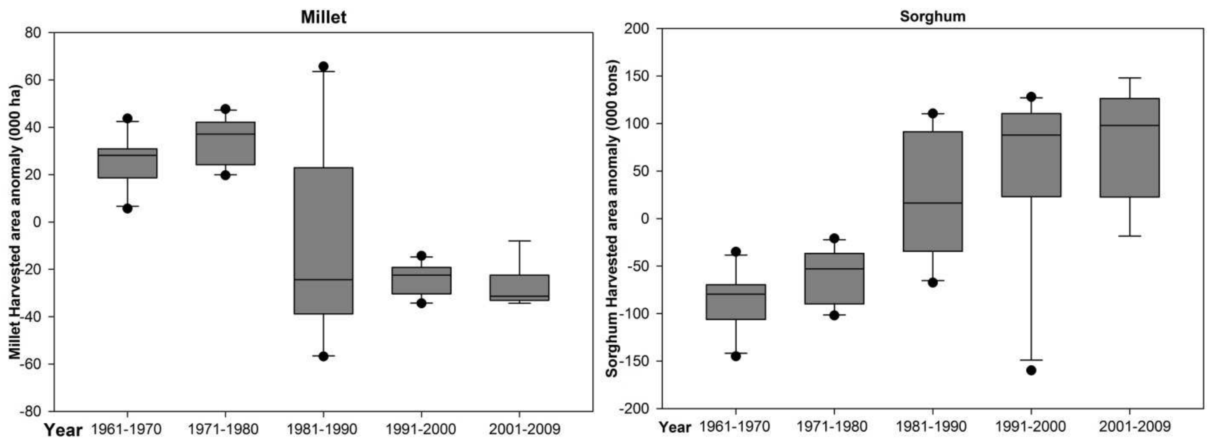


Figure 36(a & b). Showing decadal crops harvested areas anomalies impact of climate trends (1961-2006). The negative values show loss in harvested areas. Error bars show 95 % confidence interval.

6.3.2 Correlation analysis

Growing season rainfall, minimum temperature and maximum temperature were all positively related to millet and sorghum yields although the R^2 values were low. The trend in maximum temperature has a larger effect on the yields than either rainfall or minimum temperature and are all shown in figure 37-39 respectively. The correlation analysis between yield anomalies for millet and sorghum were positively correlated but weak with all the variables with the highest correlations attained for maximum temperature trends. For millet, Correlations between yields and minimum temperature (R^2= 0.21) was weaker than with the other climatic variables rainfall (R^2= 0.34) and Maximum temperature (R^2= 0.21). Similar results were obtained for sorghum with correlations between yields and rainfall (R^2= 0.22) minimum temperature (R^2= 0.11), maximum temperature (R^2= 0.29) respectively.

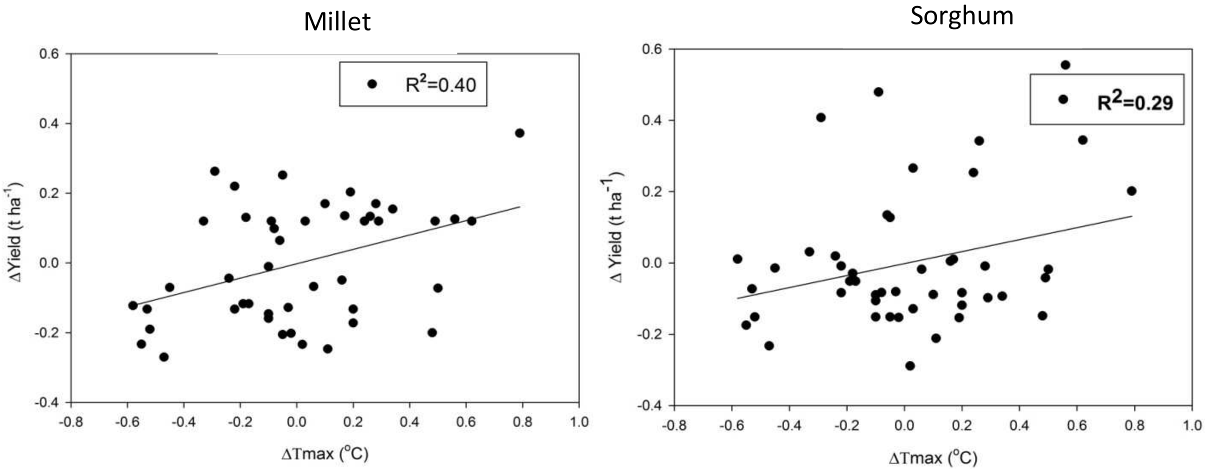


Figure 37(a &b). Scatter plots of Change in crop yields Vs Change in maximum temperature for millet and sorghum. Best fit regression line and R^2 are shown with significant correlations with yield changes ($p< 0.05$).

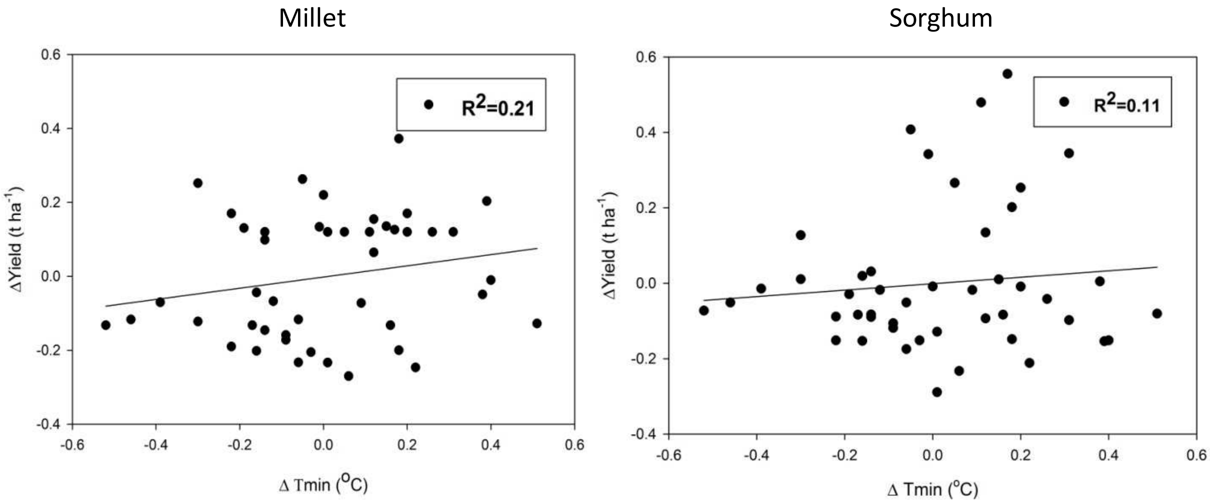


Figure 38(a &b). Scatter plots of Change in crop yields Vs Change in minimum temperature for millet and sorghum Best fit regression line and R^2 are shown with significant correlations with yield changes ($p< 0.05$).

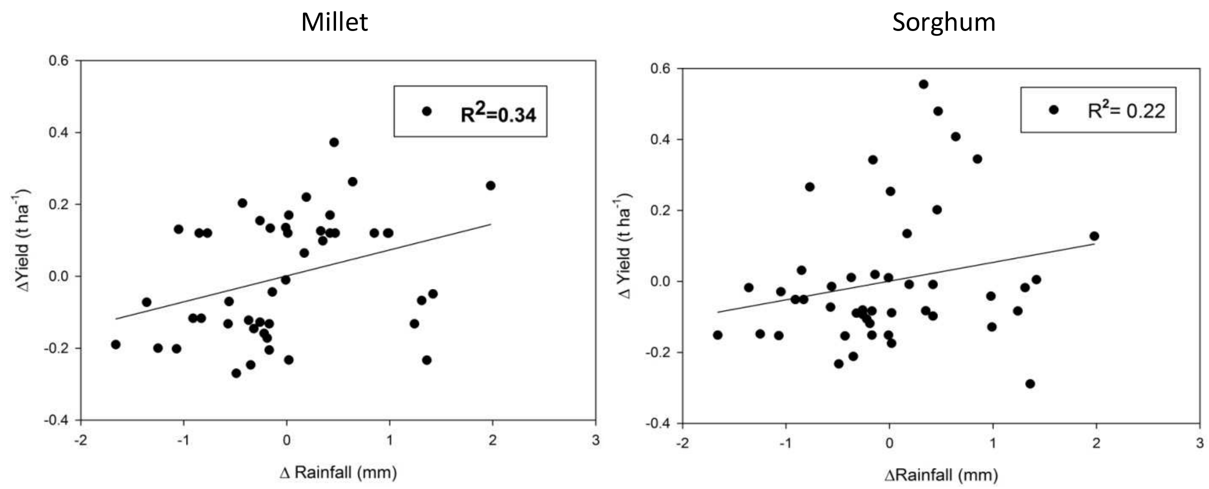


Figure 39(a &b). Scatter plots Change in crop yields Vs Change in rainfall for millet and sorghum. Best fit regression line and R^2 are shown with significant correlations with yield changes ($p< 0.05$).

6.3.3 The Regression model

Multi linear regression function using climatic variables (rainfall, maximum and minimum temperature) anomalies showed that the yield of millet was highly correlated to climatic variables compared to yield of sorghum.

For millet, the predictor accounted for 24% of the variations in yield and was significant at a 95 % confidence interval, unlike the 12% in sorghum that was viewed as insignificant (Table 16). The inclusion of the sole non-climatic predictor variable (the areas harvested) into the model, R^2 value for millet increased to 0.59 while no changes were observed for sorghum. Harvested areas accounted for 59 % of the observed yield variance in millet. The intercepts of the regression represents the average yield change with climate held constant. For millet, the average yield change was +4.6 ± 165.6 t/ha for the time of study while that for sorghum was -0.52 ± 275.7 t/ha.

Table 16. Results of multiple linear regression model based on anomalies of yields (t/ha) and climatic variables for growing season from 1961 to 2006.

	R	**R^2**	**SE**	**df1**	**df2**	**Sign.F**
Millet	0.48	**0.233**	1510.1	3	42	**0.010**
Harvested Areas*	0.77	**0.588**	1120.5	4	41	**0.000**
Variables	**Intercept**	**Std .Error**	**Rainfall**	**Min. Temp.**	**Max.Temp**	**Haversted Area**
	4.6	165.5	142.6	-1174.2	1143.4	0.04
Sorghum	0.35	0.119	1843.4	3	42	0.015
Harvested Areas*	0.35	0.119	1186.7	4	41	0.257
Variables	**Intercept**	**Std Error**	**Rainfall**	**Min. Temp**	**Max.Temp**	**Haversted Area**
	-0.52	275.7	411	-1063.7.8	-1117.8	-0.00

* Shows the inclusion of harvested areas as the sole non-climatic variables in the model.

6.4 Discussion of results on climatic variability and subsistence crop productivity

The positive relationships between climatic variables and crop yields indicate their role in determining yields under changing climate. Higher correlations obtained for the maximum temperature with yield indicate just how important this variable might be in the growth period of the crops due to the rainfall variability and uncertainty between May-August in the Sudano-Sahelian region of Cameroon. Crop responses to temperature depend on the temperature optima for photosynthesis leading to growth and yield which may vary for different crops (Conroy et al. 1994). Changes in short term extremes can be critical essentially if they coincide with key development stages. The reproductive stage is very sensitive to temperature as it has an influence on the enzymes responsible for photosynthesis. Enzymes reactions and gene expressions might impact carbon assimilation and eventually crop yields. (Gornall et al. 2010). Plant reproductive stage is very sensitive to temperature whereby at low temperatures enzyme activities are delayed causing antithesis which could affect final yields of crops (Bannayan et al. 2004). At higher temperatures, plant photosynthetic proteins may be denatured, with temperature extremes during flowering can also reducing grain or seed numbers (Matsui and Horie 1992). These findings complement previous studies on drought impacts on crop yields whereby Lobells (2011) recently reported a loss in maize yields of up to 40 % with a 1 % warming in arid regions. Dell et al.

(2008) predicted that annual increase in temperatures by 1 degree centigrade have a far- ranging negative effects on staple crops of rural farmers. Changes in temperature also have an effect on the evapo-transpiration (Wheeler et al.2000).

Differences in climate uncertainty between millet and sorghum yields reflect the fact that individual crops responds differently and develop different mechanisms under stress climatic conditions to continue their growth. Pierce and Raschke (1980) described that some plants have morphological characteristics which help to reduce absorbance of radiation. Some simply increase their root lengths density by penetrating deep into the soil to reach moisture thus enhancing water absorption. Climatic variables had more impact on yields of millet than for sorghum. Millet is considered more efficient in utilization of soil moisture than sorghum. It is hard and can grow in very hot dry areas and on soils too poor for sorghum. Generally it fits the same area of adaptation as sorghum, except that it is somewhat more drought tolerant and matures early. The attributes it has includes its fast root development, sending extensive root both laterally and downward into the soil profile to take advantage of available moisture and nutrients.

Attributes in millet that make it more productive than sorghum in low soil-water situation includes: - its deep root penetration abilities, root systems well developed and specialized cell walls that prevent desiccation. Seetharama et al. (1984) found out that lower yields of sorghum than in millet are caused by the differences in plant leaf area. During antithesis stage, leaf area is larger in sorghum than in millet plant in same area, thus higher water stress for the former. Since the stomatal and transpiration in millet is obviously less affected under water stress and recovered faster upon relief of the stress than in Sorghum (Subramanian). This gives the probable physiological base of a better adaptation of millet in the dry Sudano-Sahel of Cameroon. Oosterom et al. (2001) also reported in his comparison of physiological responses of millet and sorghum that, the former has the ability to undergo tillering. Tillering is an important adaptive feature in millet to unpredictable growing conditions in dry areas of semi-arid regions. That could account for the variations in both crop yields.

The drops in yields for both crops in the 60s, 70s and 80s could as well be attributed to the prolonged Sahelian droughts that affected this region from the late 1960s to 1980s with tragic consequences on the people and economies (Serigne et al. 2006; Biasutti and Giannini 2006; Dai et al. 2004).

Nonetheless, Sorghum is also not very sensitive to water shortages and in the case of the Sudano Sahelian region of Cameroon, they are mostly grown on black cotton soils with high water holding capacity. Sorghum is more cultivated than millet but recent increase in yield trends for millet with decrease in harvested areas are indications that there are other factors contributing to this trend. This is in agreement with Larrson (1996) who found that yields of sorghum and millet decreased with increasing harvested areas.

It is worth mentioning that the addition of harvested areas as a predictor variable did not improve the yield variance for sorghum although an aggregated 59% yield variance was observed for millet with the climatic predictors included. The strategy of increase in harvested areas was not effective in changing the yield variance for sorghum, and is an indication that sorghum farmers do not have the capacity to manage larger farm areas (Ouedrago et al. 1996). The intercepts of the regression represents the average yield change with climate held constant. For millet, the average yield change was 4.6 ± 165.6 tha^{-1} for the time of study while that for sorghum was -0.52 ± 275.7 tha^{-1}. The substantial uncertainties associated with the regression estimates demonstrates the inherent difficulty in statistically separating climatic signals in yield trends (Lobells and Asner 2003), resulting from a combination of imperfect correlation between yields and growing season average climatic conditions. However these results still corroborate with those of Peng et al. (2004)

Additionally, the unexplained variances in the regression analyses most probably were due to factors not evaluated in the model. This finding is in line with Lobells et al. (2006), who analyzed historical climate changing trends with yield trends and observed that just a little if any of the yields trends for a range of perennial crops in California could be attributed directly to climate. Such unexplained variables could include crop management practices, introduction of new cultivars and varieties, disease resistant controls, carbon dioxide fertilization, possible technological changes as well as population influence. This concur with the findings of De Wit (1992) and Bindraban et al. (1999) whereby they found out with detailed analyses that climate (water) in semi- arid Sahel region is not just the main limiting factor. Poor soil fertility (nitrogen and phosphorus shortfalls at crucial times in the growing season) limits growth rate and yields. Breman et al. (2001) confirmed this via field experiments.

Although most of the points highlighted above have been thoroughly discussed under the sub-section of farmers' perceived adaptations and constrains to climate change, population growth to an extent might have impacted crop yields. Increase in yields of millet with increasing harvested areas implied that more population is engaged in the planting of the said crop. Human population increase must have improved on the yields due to man-power inputs during land preparation, sowing, weeding and harvesting. However, yields per hectare have remained flat or have declined in places where production has expanded into more marginal areas. Ruben et al. (2006) reported that in most sub-Saharan African countries, the total food production increases for most staple cereals are have been down to the expansion of cultivation areas.

Improving management practices are capable of increasing grain yields significantly for both subsistence crops. With most croplands been marginal in terms of soil fertility, the use of crop rotation, crop residues, intercropping, organic fertilizers, manures, soil conservation methods, and water harvesting techniques are all omitted variables that could have helped the small holder farmers in improving on crop yields. Kumar et al. (2002) identified on-farm priming of sorghum, millet and maize as a low cost, low risky technology that can readily be adopted by resource poor farmers. The maintenance of crop residues on field enhances the effective fertilization and tillage has been reported by Klaij and Ntare (1995). Coulibaly et al. (2000) had a similar result whereby crop residue management had apparent effects on pearl millet productivity. Its incorporation increased pearly millet grains in fields.

Although agriculture in the Sudano-Sahel is rain-fed, irrigation practices particularly around the rivers Benue, the Mandara Plains, and The Lake Chad area could be a reason for increase in crop yields. However, with the very few water bodies present in this reason, irrigation practices could account just for an iota in the over yield changes. This finding concur with those of Pray et al. (2007) who found out that even though sorghum yields have dropped, in India, irrigation has no role to play when it concerns yield increases because about 95 % of the crops are grown in non-irrigated or rain-fed conditions.

Other factors such as the introduction of improved cultivars, new cultivar and varieties must have accounted for the variation in yields of both crops. Rao et al. (1996) reported the fact that pearl millet from Cameroon produce large pikes and grain than that from other Malawi, and Burkina Faso. Its diversity is relatively more compared to the diversity in many other African millet. Due to this, it has evolved in response to diverse agro-climatic condition in which it is grown in Cameroon. Sudano-Sahelian farmers usually select large, compact spikes free from diseases for sowing the coming season. Millet, being a cross-pollinated crop, natural crossing and selection of locally adapted material over generation must have enabled evolution of diverse types. Diverse types from Cameroon must have been used to produce improved cultivar adapted to harsh conditions for stable and sustainable millet production, hence yield improvements (Andrews and Kumar 1992). In the case of Sorghum, since 1987, the predominant new cultivar has been the cultivar S35. Despite the presence of this cultivar, the lack of information, inadequate seed supplies, the preference for locals and decreasing soil fertility, bird damages, insects and pest are some of the constrains influencing the technological adoption of sorghum cultivars (Camara et al. 2006).

Since the start of the new millennium, yields of subsistent crops have been showing downward trends. This could be associated to the CO_2 fertilization effect. Elevated CO_2 levels would however benefit fewer of such crops. CO_2 have a complex effect and composition of natural plant communities and have major implications for plant physiology and growth. The effects of elevated CO_2 levels are not uniform within natural plant communities. CO_2 physiological response varies between species, and in particular, two different pathways of photosynthesis (named C_3 and C_4) have evolved and these affect the overall response (Gornall et al. 2010). Millet and Sorghum are both C_4 crops and have optimum photosynthetic response at higher temperatures (30-35^{o}C). CO_2 is an input in photosynthesis, which uses the energy from the sun and water to produce carbohydrate and Carbohydrates ($C_6H_{12}O_6$) and oxygen (O_2) as byproducts. There are indications that key factors of quality of agricultural products may decrease under increased CO_2 (for example by reduced protein content Taub et al. 2008). Some crops grown under elevated CO_2 have been found to be more susceptible to insects and pest (Dermondy et al. 2008) or displaced reduced ability to assimilate Nitrogen. In addition, most weeds for millet and sorghum are C_3 plants and at higher CO_2 levels C_3 outperforms C_4 plants (Ringius et al. 1996).

So weed competition with millet and sorghum are likely to increase resulting in decrease in yields of both crops as it has been during the last 5 years.

6.5 Results of the impacts of non-climatic factors affecting crop productivity

6.5.1 The dynamics of land use and land cover types in the study areas of the Sudano-Sahel

By using the application of image classification methods, 5 major land use and land cover types were identified in the hotspot chosen in the Sudano-Sahel study area. Each of these classes has been described in table 17 and they include: - settlements, farmlands, light vegetation, bare soils and water bodies.

Table 17. Description of each land use land cover type in the study area.

Land use and Land cover classes	**Description of each class**
Settlements	Areas allotted to settlements patterns
Farmlands	Allotted areas of subsistence farming and other /rain-fed cultivation,
Light Vegetation	Grasslands and savannah vegetation with bushes mixed with patch trees, usually used for grazing and browsing.
Bare Soils	Are parts of the land surface which is mainly covered by bare soil and exposed rocks.
Water Bodies	Allotted to wadis or streams or rivers

The extent of Land use change in the Maroua study area

As indicated in figures 40 (a &b), in the Maroua study area, the greatest share of land use and land cover from all classes are farmlands, covering an estimate of 32% of the total land area. Light vegetation and bare soils cover an aerial size representing 29% and 27% respectively of the total area in 1987. Settlements covered a rough estimate of 12%.

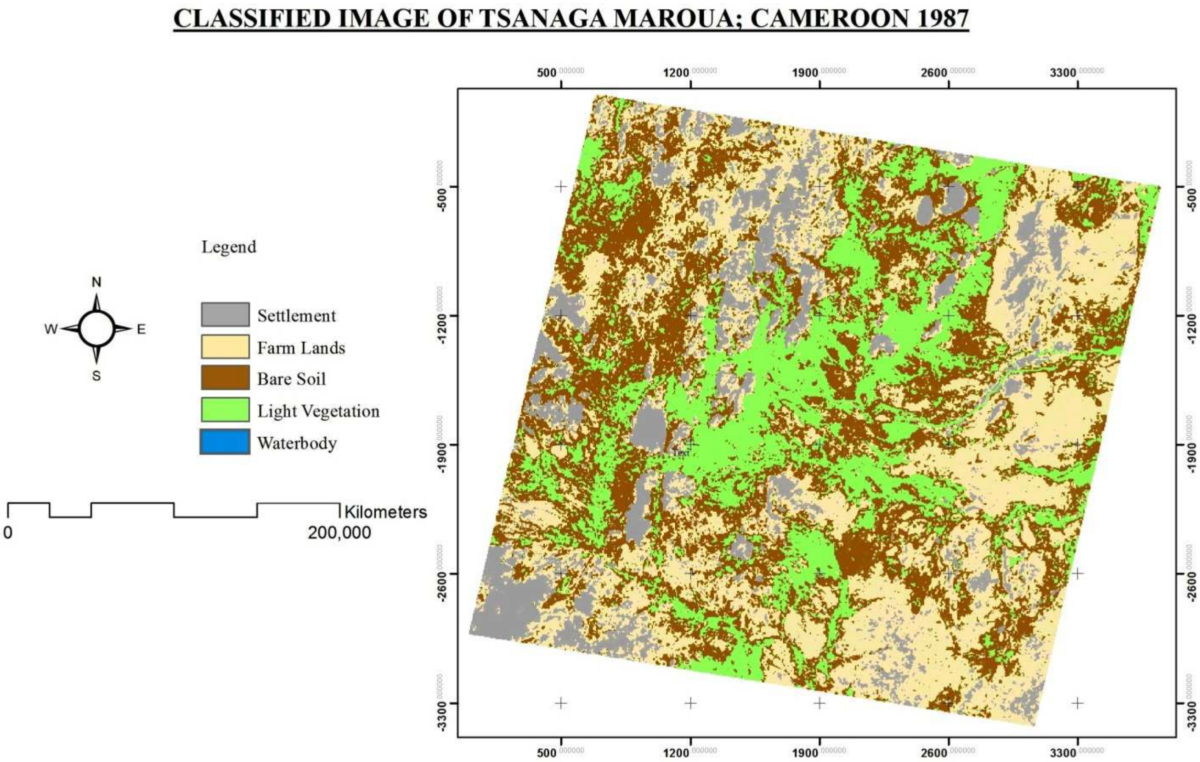


Figure 40 (a). Land use and land cover of Mayo Tsanaga (Maroua) 1987

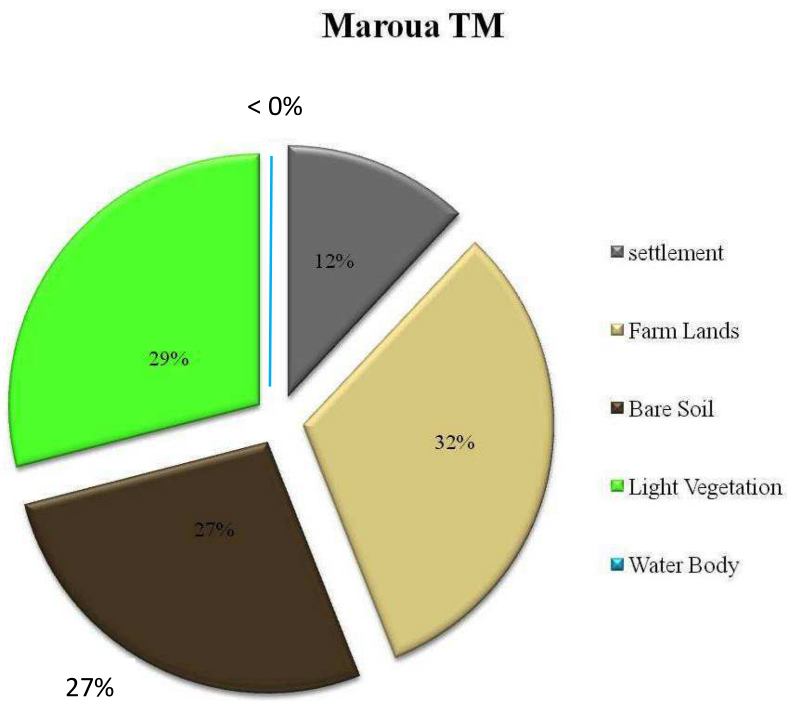


Figure 40 (b) Aerial coverage and percentage land use types of Mayo Tsanaga (Maroua) 1987

On the other hand, the Enhanced thematic mapper (ETM+) portray that for the Maroua study region, light vegetation instead accounted for the greatest share of the aerial size of land use and land cover (51%). The farmlands dropped to 22, with settlements increasing to 16%, while bare soils also significantly decrease to just 10 % to the total surface area, and finally water bodies increasing by a percentage on figures 41 (a &b).

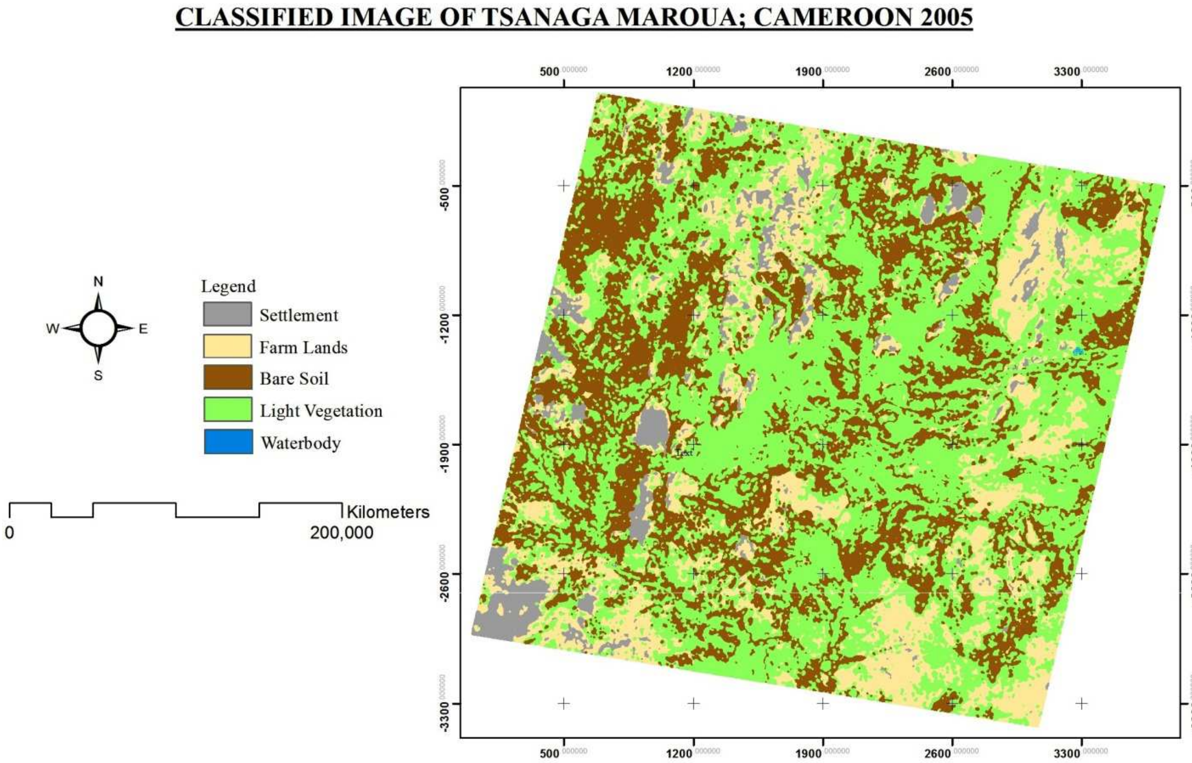


Figure 41(a). Land use and land cover of Mayo Tsanaga (Maroua) 2005

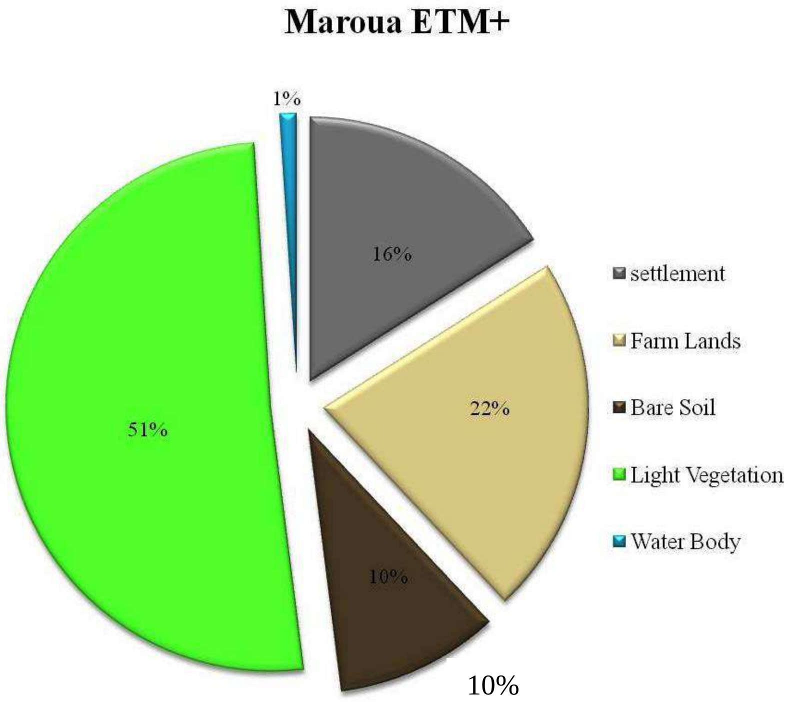


Figure 41 (b) Aerial coverage and percentage land use types of Mayo Tsanaga (Maroua) 2005

These highlighted results were quite interesting as the 10% drop in subsistence farmers' farmlands could be attributed to the rapid growth in the population of the Grand Nord (Stephenne and Lambin 2001). It therefore indicates that farmlands were no longer productive and there was the tendency for the rural population to leave these areas they cultivated and moved to other fertile area (Fotsing 2009). Settlement increased by 4%, an indication of the rapid population growth leading to the development of settlement colonies in the study area. Rapid population growth tends to intensify the stresses that humans place on the ecosystem as the population dynamics in the Sudano-Sahel show a 5 percent increase, implying the driving force in the observed land use and land cover dynamics. The drop in bare soil areas reduced by 7% coupled with a very significant increase in light vegetation for up to 24 % was very conspicuous. These two changes could be accounted for by the fact that, the images of 1987 were taken during the era of the Sudano-Sahelian droughts during the mid-1980s; drought affected the area causing severe hunger and famine. The findings corroborate with those of Tingem et al. (2008) and Molua (2008) who both described the Sahelian drought periods.

The improved vegetation cover on the other hand could be attributed to the recent increase in rainfall as shown on the SPI trend lines. The presence of rainfall could revitalize droughts in the region. Increase in rainfall allows more plants to grow, which in turn increases precipitation even more. Plants transfer moisture from the soil into the air by evaporation from their leaves and hold water in the soil close to the surface, where it can also evaporate. The darker surface of plants compared with sand also absorbs more solar radiation, which can create convection and turbulence in the atmosphere which might create rainfall (Phillip Mueller 2011). This vegetation effects have been said to account to around 30 percent of annual rainfall in the Sahel (Van Noorden 2006). The spectacular greening of the Sudano-Sahel could as well be attributed to the current rising trends in carbon dioxide concentrations. The aerial fertilization effect of the on-going rise in the atmospheric carbon dioxide concentration increases greatly the productivity of plants. The more CO_2 in the air, the more plants grow better. Rise in atmospheric CO_2 also has ant-transpiration effect, which enhances the water-use efficiency of plants and enables them to grow in areas that were once too dry for them (Iso 1995). These findings however warrant further thorough investigations.

Another very convincing reason for the Sudano-Sahel improved greening could be the Operation Green Sahel Initiative that was launched by the government in line with the United Nations Environment Program (UNEP) Billion Tree Campaign on the Sahara belt. This afforestation campaign substantially contributed in reducing the farmlands and bare soils. Most recently, the organisational chart of Ministry of the Environment and Planning (MINEP) created, the Department of Restoration of Nature that so far has been working in habitat restoration measures and have galvanize the attainments of the motives of the "Operation Green Sahel". The slight increase in water bodies could be attributed to the presences of ephemeral streams or wadis. These are caused by the variability in the rainfall patterns, whereby intense wet spells have the likelihood of leaving behind patches of water (wadis), locally called Kouri in the Hausa language.

6.5.2 Analysis of land distribution and trends in farm sizes

Small farm sizes dominate the share of total household farms. As shown on table 18 from the 34.260 km^2 land area of the far north region (Maroua), 4117 km^2 were cultivated in 1996. As the population increased by 5 percent, the cultivated agricultural land area also increased to about 5764 km^2. A similar increased was also observed for the North and Adamawa regions as farm sizes reduced for all 3 Sudano Sahel regions.

Table 18. Agricultural land area distribution and evolution of average farm sizes

Region/ Total Area (Km^2)	Year	Population	Poverty Index of Population (%)	Cultivated Agricultural Land (Km^2)	Percentage Change in Agricultural Cultivated Area (Km^2)	Average farm size (hectares)
Far North (Maroua) 34 260	1996	2 467 000	49	4117	4.8	<2
	2010	3 480 414		5763.8		0.5
North (Garoua) 67 808	1996	1 000 000	44	1500	1.8	1.5
	2010	1 800 000		2700		0.5
Adamawa (Ngaoundere) 61 992	1996	500 000	37	850	1	<1
	2010	850 000		1445		1

Although agricultural cultivated land areas have increased, the average farm sizes tend to decrease considerably. This is a clear indication that with increase in population, there is the tendency for bare soils to be converted into farming lands. Land holdings are becoming increasingly sub-divided and parceled as a consequence fragmented. In the Maroua study region alone, the average farm size shrank from less than 2 hectares in 1996 to 0.5 hectare in 2010. It is worth mentioning that land fragmentation is an obvious and common feature of agriculture in the Sudano-Sahel. In this situation a single farm has a number of parcels of land averaging less than

2 to 0.5 hectares. Fragmented lands are commonly seen where due to the increasing population and the expansion of settlements with family lands are shared amongst the number of households. The parceling of these lands is especially seen in polygamous homes where land fragmentation practices are exacerbated. At the household level, the inheritance from parents to sons, sons getting married and sharing the lands with wives, individuals equally sharing resources including land when divorcing, and land redistribution play significant roles such that small-sized farms are likely to be more fragmented.

Land fragmentation thus has a negative impact on the degradation of land and concomitantly crop productivity, thus increasing the pauperization of the population. The above finding concur with those of Nagayets (2005) who found a similar reduction in the average farm sizes in small holder farmers some selected less developed countries as the population increases. Therefore agricultural activities and livelihood options for the rural poor are affected not only by climatic conditions, markets, infrastructure, physical conditions, but also by human population impacts pertaining to the pressures on land.

6.6 Analysis of questionnaire survey

This section analyses farmers' perception of climate change and adaptation methods developed and implemented by subsistence farmers. With most of the interviewed population being subsistence farmers, they engage themselves in various agricultural activities for their livelihood. Apart from agricultural activities, other source for sustenance includes petit trading with articles like salt, maggi, bonbons etc. Average household own about 2 plots; the plots around the vicinity of the homes; and those the main plots "Champ" usually miles away from the homes. Plot sizes range from 1-2 hectares depending on the family size. Agricultural practices vary from slash and burn, shifting cultivation, mono-cropping, pastoral nomadism and mixed farming. Dominant food crops include:-millet, sorghum, maize, onions, and groundnuts. The cattle include sheep, goats, zebu cows, horses and donkeys.

6.6.1 Subsistence farmers' perceived adaptation responses

In instances where climate change is perceived, farmers perform a plethora of practices in order to cope with the changing environment. Quite a number of adaptation strategies have been adopted by subsistence farmers in the wake of the varying climate and are shown figure 42, with about 21% of the respondent saying they changed planting dates as adaptation strategies. Some 20 % of the respondent cultivated different crop varieties. Another adaptation strategy perceived by the farmers was the migration from the rural suburbs to urban areas in search of greener pastures. Some 17 % of the farmers have increased their cultivation areas of land while about 16 % use local indicators. Some 14 % have perceived switching from crops to livestock as an option, while on the other hand just 1% switched the opposite way .i.e. from livestock to crops. Some 6 % of respondent perceived the search for off-farm jobs as another adaptive means, 7 % used fertilizers with 8 % seeing soil conservation strategies as an adaptation measure. The use of irrigation was opined by 4 % of the respondents while 7 % of farmers have even hinged on daily prayers for better climatic conditions.

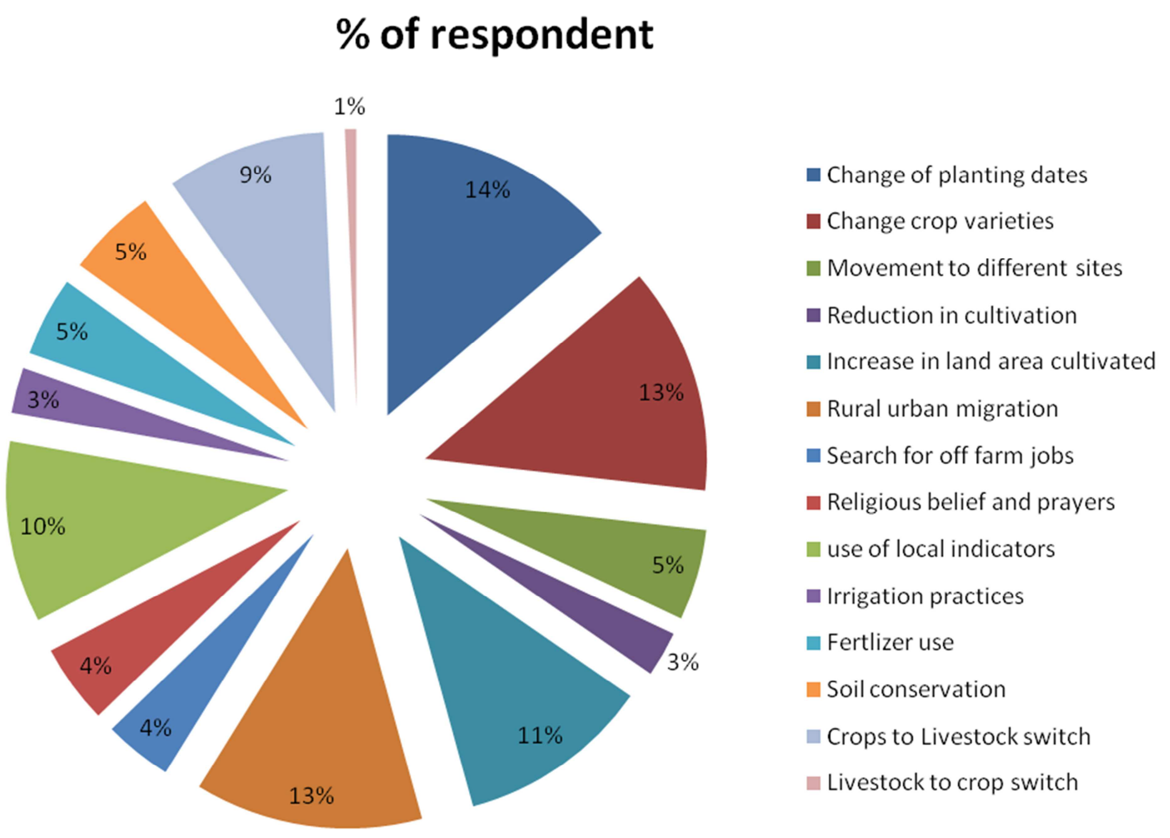


Figure 42. Farmer's perceived adaptation practices to climatic variability and changed in the Sudano-Sahel of Cameroon

6.7 Discussion on subsistence farmers perceived adaptation practices on climatic variability and change

Perception is a necessary prerequisite for adaptation. Perceptions are considered to be important as they are regarded as critical determinants of necessary precondition for adaptation (Koch et al. 2006). From the findings, subsistence farmers' perception on climatic variability and change are based on assessments of mainly temperature and rainfall as they are experienced within the localities. Although they appear to be well aware of climate change, few seemed to actively take steps toward adjusting to the changing climate. Subsistence farmers in the Sudano-Sahel have to an extent been able to constantly cope with and adapt to the challenging environmental conditions. They have developed innovative responses to difficult or changing conditions. It must be reiterated that the strategies pointed out by the subsistence farmers are based on lessons learnt from previous climatic stresses and have been handed down from generations to generations, with most of the strategies having some similarities for most sub-Saharan African countries (Reij and Waters-Bayer 2001). The main adaptation strategies of farmers identified in decreasing order of respondent include change in crop varieties, changing planting dates, rural – urban migration, increase in cultivated land area, switching from crops to livestock, the use of local indicators, religious beliefs and prayers, irrigation practices, reduction in cultivation, search for off-farm activities and just to list a few.

6.7.1 Switching crop varieties

As an ex ante adaptation strategy, subsistence farmers have developed the tendency of switching crops varieties as climate changes. They seek to grow crop varieties that are with different sensitivities to climate. Farmers' response indicated that this has been a viable option for adaptation. Farmers' choices on what to grow depend partly on climate, though at times, year to year crop choices are likely dictated much more by expected prices at harvest than climatic conditions (Tingem et al. 2008)

The reason for the positive farmers' perceived response that crop switching is a viable option for adaptation could be associated to the conspicuous presence of the agronomic research institute although supplies have been limited. Moreover, over the past two decades, improved sorghum and millet technologies have been developed for the entire West and Central Africa by ICRISAT that are high yielding, more productive, short cycle, pest-disease resistant as well as drought tolerant varieties. Common in the study region was the High Yielding Variety (HYV) of millet and the S35 variety of Sorghum. Farmers in the Sudano-Sahel have substituted short duration S35 for their long cycle landraces (Djigari, Nadj-dadja, Kouran and Wakas varieties). Farmers' preferences for the S35 over the traditional varieties have been overwhelming due to its early maturing and high yielding with good fodder quality characteristics. These findings concur with those of Yapi et al. (1999) who studied that S35 varieties have an average yield of up to 51 percent higher than the local varieties.

Lacy et al. (2006) showed how subsistence farmers in Mali responded to shorter rainy seasons by using short cycle varieties of sorghum although long cycle varieties were farmed as they gave higher yields and had better taste. These short duration traits of S35 are an advantage in drought prone areas where farmers long cycle traditional landraces often fail when rains come late. More so, their required changes are simple, familiar and easy to implement locally using family and animal labor Therefore the act of switching crops and using new crop varieties has really been a viable option since most farmers tend to welcome the new varieties.

Recently, ICRISAT launched the HOPE Program (Harnessing Opportunity for Productivity Enhancement) where improved varieties of millets and sorghum will be disseminated to households in the Sahel. Apart from the planting of millet and sorghum, farmers in this region have also switched to the planting of groundnuts, maize sesame, onions and maize. They also grow lower value but drought tolerant crops such as cassava. Kurukulasuriya (2006) and Gbetibouo (2009) also have also reported the same for other parts of Africa.

6.7.2 Changing of planting dates

Farmers in the Sudano-Sahel have an anticipated adaptation measure for which adaptation actions to climatic variability and change are taken. Their dependency on rain-fed agriculture makes them to maintain flexibility with regards to input decision until uncertainties about weather realizations are reduced, for instance by shifting when crops are planted. Shifts in planting dates are usually aimed at minimizing the effect if temperature-induced spikelet sterility that can be used to reduce yield instability by avoiding coincidence of the sensitive flowering stage with the hottest part of growing season (Sparks et al. 2000).

Most decisions on when to sow are based on a number of factors including available soil moisture, the expected timing of temperature extremes. Due to the variability and the uncertainty in the climate (weather) year to year shifts are already a demonstrated farmer's adaptation practice particularly in the Sudano-Sahel. Instead of farmers directly sowing after ploughing, they wait for the rains to come before seeds are sown. Farmers routinely shift planting dates by month or more from year to year in response to variability in when monsoon rains arrive. However, it is not really a guarantee that changing in planting dates will improve crop yields since most growing season lengths would be reduced. Historically, early sowing without the rains have caused seeds to dry up due to unexpected high temperatures. This perceived adaptation action of changes in planting dates is consistent with the works of Bradshaw et al. (2004); (Deressa et al. 2009); Tingem et al. (2008); and Molua (2008); Gbetibouo (2008); and Nhemachena et al. (2007).

6.7.3 Crops to livestock switch

Since rain fed crops are constrained by the harsh climate, it is apparent expanding at the expense of livestock numbers, which are more or less sensitive to climate factors. To supplement the recent shifts from crop to livestock as a perceived adaptation strategy, the increase use of cotton cake as feed for cattle has increased. The presence of parastatal organization Société de développement du coton du Cameroun (SODECOTON) operating in the North and the Far North regions provides a constant supply of these feeds. Moreover, since the 1994, the exportation of cotton seeds cakes to the Scandinavian countries stopped. This implies that the local cotton cake consumption produced by Sodecoton has been wholly local. This is reflected in the local sales of these cattle feed that has since then been booming (Figure 43). The rise in cattle prices could also be a justification for the subsistence farmers perceiving the switch to livestock as an adaptive strategy. Farmers keeping cattle as savings from crops and investment capital has been a common observed culture in the Sudano-Sahel of Cameroon.

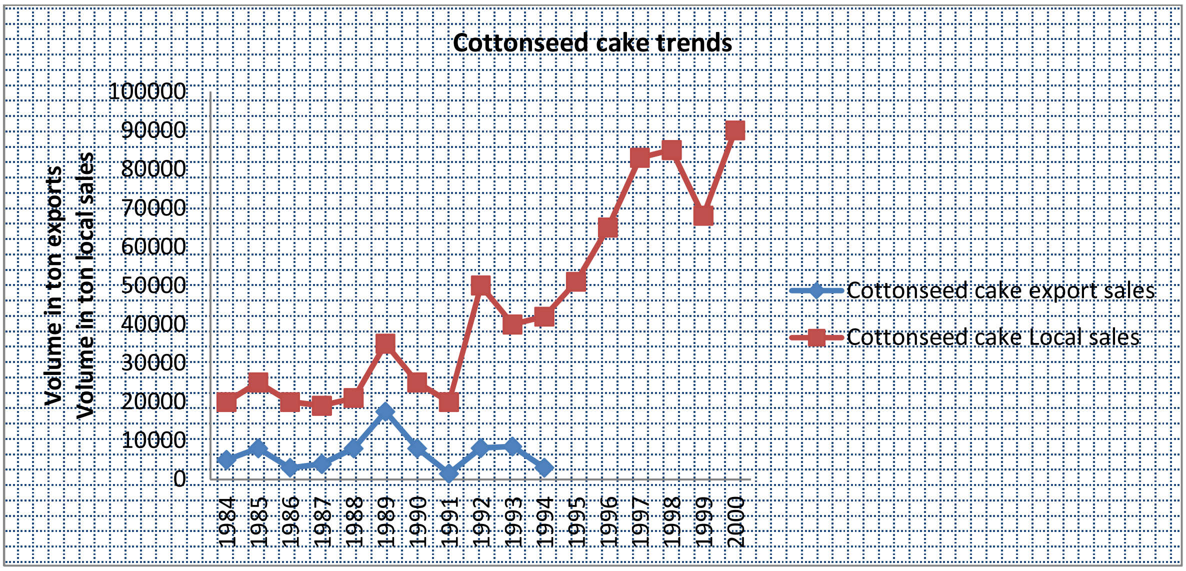


Figure 43. Trends in Local and export cottonseed cake sales in the Sudano-Sahel (Source: SODECOTON)

6.7.4 Rural urban migration/ Search for off farm jobs

With subsistence farming extensively carried out in the rural areas with productivity determined by water availability (rain-fed agriculture), the tendency will be for movements from less favorable to better conditions. The movements from rural areas to urban areas perceived by subsistence farmers as an adaptation strategy could be accounted for by the demand pull and supply push factor whereby with the former, modern sectors of production, which generally are located in the urban area, have higher rates of productivity and monetary reward than the traditional rural agricultural sector and hence attract rural migrants (Barrios et al. 2006). The supply push on the other hand referring to the possibility those other factors directly affecting the rural sector have favored population movements towards cities but not necessary result in productivity improvements. They may include direct determinants of agricultural production and in the case of the Sudano- Sahel rainfall was the main factor. Climatic variability and change is an important supply push factor in the determination of urbanization in this work. Barrios et al. (2006) also reported that although climate per se is seldom the direct root of migration except in extreme cases like floods and droughts, it clearly can however; exacerbate difficult living conditions at the margin of subsistence.

The observed extreme climatic events from the results of the SPI, farmers' perception of increase in temperature and drops in rainfall are all abrupt changes likely to have caused the movement of the population to urban areas. Cameroon in general and the Sudano-Sahel in particular the urban population annual growth rate has increased by about 3.7% ; the annual growth rate of change of urban population increasing by 1.7 % while the annual rate of change of rural population is -1.88 % (see figure 18 on page 33 for more details (WUP 2011). It is worth mentioning that this increase in urban population with drops in rural population is not coupled with an improvement in economic wealth but rather the fact that internal migration has been a major factor fuelling the growth in African cities (Fay and Opal 2000). This study is in line with those of Myers (2005); and Afolayan (1999) who all linked the concept of eco refuges or environmental refuges, where environmental conditions may influence socioeconomic activities (conditions) and hence migration. Reports by Turner (2002) indicate that during the Sudano-Sahelian droughts, young men had departed, leaving behind old women, men and children, with many of them moving to the cities for greener pastures. They are attracted by the hope of better life in the cities but they have little chance to achieve their dreams. As an addendum some of the young men in the Sudano-Sahel even cross the Sahara and try to get into Europe for better lives.

To substantiate this, there exists a pool of industries in the Sudano-Sahel that one could convincingly account for that demand pull of rural population to the cities. These include the Cotton oil plant in Kaele, the bleaching and dyeing factory in Kaele, the Cement Factory in Figuil. Limestone is also mined in Figuil, Tin is ored at Poli. Leather weathering is an important industry in Ngaoundere.

Off-farm incomes activities could as well play a role in the economic livelihood of the farmers. Since non-agricultural income sources are less sensitive to climate change, farming activities that diversify farmers' incomes are perceived as an adaptation strategy. Farmers in the Sudano-Sahel do petit trading, selling sugar, salt, and magi with very low capitals. This could be a very plausible way through which farmers could adapt to climate change but problems arise when such as activity is taken as a low-return coping strategy. This is the case with Sudano - Sahel where the total capital for most of such petit business are so meager that can really function well as a backup in case of climatic impacts on agricultural activities.

6.7.5 The use of local Indicators

The use of local indicators has a long stand traditional indigenous knowledge that enables farmers to live in a changing climate. Before the advent of modern scientific methods of rainfall forecasting, Sudano-Sahelian farmers have developed intricate systems of gathering, predicting and decision making relation to weather. These could be seen as a platform to promote participatory pathways for addressing various climate change dimensions.

The range of indicators widely used to predict includes examples like the nesting behavior of birds, and incidences of insects, timing of fruiting of certain trees, the flowering of specific trees, the water level in streams and ponds, the proliferation of obnoxious weeds, and observed soil fertility levels. The migration of the bees and birds from north to south, and the appearance of rare bird species, with incidences of insects such as the locust, and when cattle in the Sudano-Sahel look weak all the time, these are all local indicators of the likelihood of droughts.

Moreover, local farmers use local weather conditions to prepare for droughts. Examples include the strong winds blowing, unusual coldness and low temperatures, thunderstorms during the onset of rains foretell subsistence farmers that the season will be very dry. Another good drought forecast indicator has been the flower and fruit production of certain local trees, when poor giving a reason for apprehension. A good example is the shea tree *Vitellaria Paradoxa Gaertn. Or (*Butyrospermum parkii and *also B. paradoxa)* or Ka´danya as it is called in the local Hausa language (Figure 44). Another local indicator plant used is the *Anogeissus leiocarpus* (Chewing stick plant). When it fails to blossom, it is an indication of harsh dry conditions. The Baobab tree *Adansonia digitata* (locally called kuka in the hausa language).

Figure 44. The Ka´danya or the shea tree (Butyrospermum parkii) used as drought forecast local indicators in the Sudano-Sahel (Source: Author)

Similar findings on local indicators as predictors of weather conditions have been reported elsewhere in Africa. In Nigeria, farmers have been able to use knowledge of weather systems such as rains, thunderstorms, windstorms, the harmattan (a dry dusty wind that blows along the Northwest coast of Africa) and sunshine to prepare for future weather. Levick et al. (2010) recently found out that termites foretold climate change in Africa after using sophisticated air-borne imaging and structural analysis, found out that by mapping where termites choose to place their mounds, the insect are providing an indicator of climate change across the region. Farmers in the Sahel of Burkina Faso believe that cold (below 15 degrees centigrade) during the dry season corresponds to abundant rainfall during the rainy season and that and that if cold begins early or ends late, the rain will be likewise. Also, intense heat during hot dry period (February to April) is believed to predict good rainfall as well.

6.7.6 Increase in land cultivated

Increase in the cultivation areas perceived by the farmers also corroborate with results obtained using the regression analysis whereby when harvested areas accounted for 59 % of the observed yield variance in millet. Implying that subsistence farmers do increase the areas they cultivate as an adaptive strategy. One of the reasons could be the decrease in soil fertility that makes farmers to perform other agricultural practices such as slash and burns, shifting cultivation. This might have accounted for this adopted strategy. The IPCC (2007) recently projected an increase in a 5-8 percent (60-90 million hectares) of semi-arid land in Africa by 2080 under various climate scenarios. Implying that with the present agricultural practices under varying climatic conditions, more land is degraded since the population tends to use every blessed means in order to search for better agricultural lands and as a consequence increased in degraded land area. These concur with the results of the remote sensing whereby vegetation and bare soils have reduced in the Sudano-Sahel, an indication of increase in population searching for marginal lands to cultivate. Countries in at high latitudes of the northern hemisphere are most likely to benefit from climate change with respect agricultural land availability, while countries at the mid and low latitudes may suffer different levels of loss of potential arable land (Zhang and Cai2011).

6.7.7 Religious beliefs and prayers

Sudano-Sahelian farmers like most African farmers have an in-built doctrine that emphasizes the subjugation of climate change concerns to fate. Farmers use typical statements such as ´´weather is god-given´´ and ´´that weather is a divine phenomenon that they are not in charge of´´ (Ajibade and Shokemi 2003). They pray all night long and offer sacrifices to their gods for better climatic conditions. Subsistence farmers constantly go to the soothsayer ´´marabout´´ who devote themselves to prayers and use talisman to restore health or social order. Subsistence communities have a long history about sacrificial obligations during prolonged droughts and when the rains fail to come. They offer goats, sheep or chicken for the marabouts to intercede the end of droughts. After a prayer of a marabout, the rains would have come. This is a common feature and does not surprise the write when some subsistence farmers hinge to prayers for better weather conditions.

Prayer ceremonies and sacrifices have been offered in most Sub Saharan countries for the rains to fall. This has been the case in Nigeria (Ukachukwu 2007). In Malaysia for instance, even the state announced it would hold prayers to beg for the rains as it struggles to cope with prolonged dry spells. Farmers formulating hypothesis about rainfall based on cultural and ritual specialists who draw predictions from divination, visions or dreams have been reported by (Roncoli et al.

2007; Mertz et al. 2009) also concur this study with his reported on the power nature of the marabouts in Sub Saharan Africa and the sensitivity of the issue as many people in the region are followers of the marabout, thus underlining the complexity of arriving at a clear understanding of the local strategies in subsistence farmers adaptation to climate change, characterized by a “cacophony” reality of social and cultural engagements.

6.7.8 The use of Irrigation

In the Sudano-Sahel characterized by low soil moisture, peaking daily temperature and runaway evapotranspiration irrigation is deemed as important adaptation strategy by the subsistence farmers to the changing climate. Irrigation delivers water directly to the roots of plants, thereby improving soil moisture conditions. Most farmers living closer to the streams and rivers do perform irrigation for plants to have constant water source.

In order to ease water constrains for crops, improved irrigation by switching from traditional to more effective systems such as drip irrigation and pipe irrigation could be crucial (Ziervogel et al. 2008). In the North of Cameroon, an Israeli Drip Irrigation technology tool kit was launched recently and could be of importance as the kit covers the plant from bottom and transforms the evaporating water back to the plant, thereby reducing water wastage.

6.7.9 Soil conservation strategy

Soil conservation is perceived by farmers as another adaptive strategy. They use fallow periods and manure to maintain the integrity of the soil. Composting is also practiced, with cow dung after decomposition serve as source of nutrients for the household crops. Other practices include the use of farm yard manure, crop rotation, green manure, crop covers, mulching, agro-forestry residue retention and just to name a few. It is worth mentioning that these practices are inherent in ecological agriculture and can reduce the negative effects of droughts while increasing crop productivity (Niggli et al.2009). Water-holding capacity of the soil is enhanced by practices that build organic matter, helping farmers withstand droughts (Borron 2006). So if farmers perceive the conservation of soils as an adaptive strategy, this could aid not only in the protection of the integrity of the soil but also in the protection of crops from drying as well as improving on their yields.

Improved agricultural practices or better agronomic practices thus far have been proven to have enormous potentials in mitigation and concomitantly the adaptation of farmers to climate change. Evidences of specific sustainable agricultural interventions have been recorded by Edwards (2006) whereby based on data from the Tigray Region in Ethiopia, having a similar climate to the Sahel, whereby the average crop yields on composted fields gave higher and sometimes double yields, than fields treated with chemical fertilizers. Also recent studies examined a global dataset of 293 examples and estimated the average yield ratio of different food categories for developed and developing countries (Badgley et al.2007). On the average, in developed countries, organic systems produce 92 % of the yield produced by conventional agriculture. In developing countries, however, organic or sustainable agricultural systems produce 80 % more than conventional farms. Organic methods have been found to hypothetically produce enough food on global per capita basis to sustain the current human population, and potentially an even larger population without putting more farmland into production.

On the other hand, Smith et al. (2007) estimated that African croplands could potentially reduce GHG emissions by 2.0-3.5 $MtCO_2e$/ha/y or a total of 52.3-91.5$MtCO_2e$/y equaling 5-9 of annual African fossil fuel emissions in 2005 (Canadell et al. 2009). In semi- arid lands for instance, agroforestry systems like intercropping or silvopasture, with 50 trees per hectare, can store 100 to 147 tons of CO_2 equivalent per hectare in the soil alone (Nair et al. 2009). In humid zones, the retention of shades and understory trees in cocoa is capable of providing vast majority of carbon stores. Rice and Greenberg (2000) found out that mature cocoa agroforestry systems in Cameroon store up to 565 tons of CO_2 equivalent per hectare.

Similarly, proper pasture management can potentially store between 110 kg to 810 kg of CO_2 equivalent per hectare in dry land and humid lands respectively (Smith et al. 2007). In managed regeneration, with 200 million trees grown in 5 million hectares of land in two decades in Niger, was capable of sequestering over 100 million tons CO_2 equivalent while providing diverse livelihood for farmers (Rinaudo 2009). Detail quantification, verification and valorization of the potentials of agriculture in Sub Saharan African agriculture in climate change adaptation and mitigation have are shown on Annex 5.Various agricultural practices ranging from cropland and grazing land management, restoration of degraded lands, manure management, pasture management and bioenergy all crucial in climate change mitigation and adaptation are outlined.

6.8 Constraints in adapting to perceived climatic changes

However, results from subsistence farmers' interviews and the discussions with extension services workers on the question "what are the main constraints in adapting to the perceived climatic variability and change indicated that many factors hindered subsistence farmers´´ adaptation to the vagaries of climatic events in the Sudano-Sahel of Cameroon. Most of the responses were more or less the same. Analysis of the constraints indicate that there are six major drawbacks to adaptation and includes: - Poverty (lack of money or credit facilities), the encroachment of the desert (poor soils), the lack of information, land shortages, shortage of manpower (labour) to work on the farms, farmers health status, non-availability of seeds, high prices and the inappropriate government policies such as supply of fertilizers and irrigation potentials. Public awareness and communication as well as high prices of basic supplies and food were highlighted as constraints.

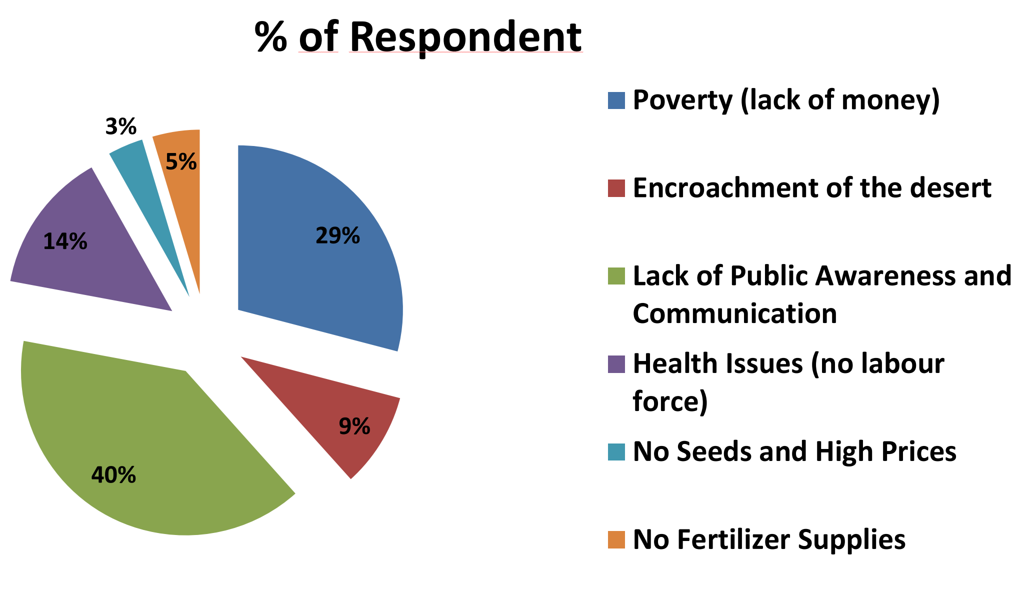


Figure 45. Constraints in adapting to climatic variability and change by subsistence farmers

6.8.1 Discussion on constraints in adapting to climatic change

The constraints to adjusting to climate change by subsistence farmers are numerous. The magnitude and extent of the impacts of climatic variability and change on subsistence farmers make it relatively difficult to come up with appropriate responses. Of the many factors that hinder subsistence farmers' adaption to climatic variability and change, most if not all could be coined under the banner of poverty. These factors perceived by the subsistence farmers render their adaptive capacities ineffective and are largely insurmountable.

Adapting to climate change is a very costly venture (Mendelson 2006). A major barrier is the lack of financial capital. This is a typical characteristic and evident of subsistence farming in the whole of sub-Saharan Africa, whereby the majorities of the people living in the rural areas are poor and have a low purchasing power. The lack of money hampers farmers from getting the necessary resources and technologies which assist in adapting to climate change. The acquisition of necessary facilities such irrigation facilities, seeds, varieties and hybrids availability, weather forecast technologies (radios and televisions) make the adaptation of farmers to variability in the climate extremely difficult due to their resource poor nature. A glaring example in the Maroua, Garoua and Ngaoundere study areas has been the high cost in the grinding of sorghum that constrained the adoption of the S35 variety. With the government no longer subsidizing fertilizer synthetic fertilizers, its high prices also limit subsistence farmers' adaptation capabilities. It is also worth mentioning that financial constraints also prevent the government from paying a more positive role in adaptation. Government agencies are often poorly resourced relative to the demands placed on them, whereby they tend to priorities other poverty reduction strategies over adaptation to climate change. There are also other impediments to the government support for adaptation that includes ineffective administration and inadequate accountability and corruption. Moreover, subsistence farming being the backbone of the economy has been socially and politically marginalized. Studies by Adger et al. (2007); Brooks et al. (2004); Downing et al. (2005); and Ziervogel et al. (2006) found out that wealthier households in subsistent farming communities are better able to act quickly to offset climate risk than poorer households.

The encroachment of the desert, poor soils and lack of land for cultivation constrains Sudano-Sahelian farmers from adapting to climate change. Land shortages have been associated with the high population pressures and desert encroachment forcing farmers to intensively farm over small plot of land. The encroachment of the desert causes the Sahara and the Sahel belts to move downwards leading to a reduction in the total area occupied by the Sudano area. This accounts for farmers' perceived constraints pertaining to adaptation to climatic variability and change and concur with the studies of Onyenechere (2010). Moreover, being in a traditional set-up, most subsistent farmers do not usually have title to farmlands but enjoy the user rights which could be withdrawn at any time by the custodian of communal land. Benhin (2006) and many other authors have identified land tenure status as one of the factors limiting farmers capacity to adapt. Another constraint faced by the subsistence farmers has been the problem of pastoralists whose cattle tend to encroach into cultivated croplands. Frequent conflicts between the herders and cropland farmers are encountered year in year out (Moritz 2010) in agricultural and pastoral systems in West Africa.

The shortage of farm labour is one of the main constraints stated by subsistence farmers impeding the adaptation to climate change. This might have led some of them to reduce their farmland (cultivated areas). Others do not even have enough energy to cultivate more land area or plots; Illnesses and diseases have constrained the farmers, with some too weak to from hunger and unable to work more than a few hours each day. This is evident by the incidences of HIV/Aids pandemic that have devastated the whole of Africa and have further exacerbated their vulnerability through loss of productive labour, knowledge, income and rising dependency burden of taking care of orphans (Yamano and Jayne 2004). Labour has also been due to migration and this has been discussed thoroughly above in some of the perceived adaptation strategies by subsistence farmers by the author. Labour constraints concomitantly hindered the implementation of some adaptation practices of soil and water conservation such as mulching, composting. These methods have the tendency for farmers to adapt and mitigate climate change thereby improving on crop yields as they are easy and less costly to be adopted (Niggli 2009).

Poor access to information, lack of awareness and inadequate knowledge on how to cope are some of the constraints to adaptation. Farmers might have knowledge of many traditional and rudimentary practices in order to cope with droughts and other stresses, but often have little knowledge of new or alternate methods due to poor access to education, training or extension services. Due to lack of education and knowledge, farmers do not want to change from inherited traditional practices to evaluate and implement new methods (Mougou et al. 2007). Most forecast information although rare, when made available to the population are poorly disseminated and delivered only shortly in advance of the forecast periods and only reach smallholder farmers in forms that they do not readily understand. The lack of information about weather or long term climate change adaptation barrier has been reported by Maddison (2006). Mark et al. (2008) argued that the lack of adaptive capacity due to constraints on resources like information may result in further food insecurity. In addition, Benhin (2006) and Enete et al. (2008) also noted further that the level of education of farmers and access to extension services are major determinants of speed of adoption of adaptation measures to climate change.

7.0 Policy implications, Conclusion, Recommendation and Outlook

7.1 Prelude

This chapter aims at presenting the policy options for adaptation and the conclusions drawn from the findings within the framework of the research aims and hypothesis. It briefly synthesizes the salient findings of the previous chapters on the impacts of climatic change on some subsistent crops in the Sudano-Sahel of Cameroon, elaborating on the vulnerability of farmers, the severity of the impacts, adaptation policy options and various actors that have critical roles in mainstreaming and implementing climate change adaptation policy options. Finally a summary of recommendations are made on adaptation options with a way forward on the future.

7.2 Policy implications

Clear warming trends, increase in the incidence and frequency of extreme events particularly droughts have been observed, fluctuation in rainfall and uncertainty in rainfall patterns, shortening of growing season, shift in the timing of rain have also been observed in the Sudano-Sahel of Cameroon and have impacted subsistence crop production with farmers altering their farming practices in order to maximize yields in new situations. In the previous chapter, several farm-level adaptation practices from subsistence farmers were identified and analyzed. However, to practice such farm-level adaptations, sustained policy and institutional level support and adaptations are required.

The process of adaptation is not new; the idea of incorporating future climate risk into policy-making is. Policy intervention may be required, however to ensure that farmers can respond when they need to and the availability of support as they consider their options. For adaptation of subsistence farming to be sustainable in a broad scale, it must be incorporated, integrated or mainstreamed into the policy apparatus of governments. An integrative approach to adaptation is imperative and has to be integrated within the broader milieu of sustainable development and poverty reduction strategies. (Kok et al.2006). The policy options should be an extension of development designed to eradicate the structural causes of poverty and food insecurity. Most of these measures relate closely to, or directly overlap with existing strategies, policies, programs (such as agricultural development, food security, livelihood maintenance, risk management and just to name a few).

The adaptation options perceived by the farmers could be grouped into four main policy classes as illustrated in figure 46. It is worth mentioning that these classes are not mutually exclusive and could be used interchangeably. These include: - Polices towards the farm-crop ecological production practices, technological development policies, farm financial management policies, social and political welfare policies. Implying that adaptation policy options geared towards technological developments could be enhanced by policy options from the financial management.

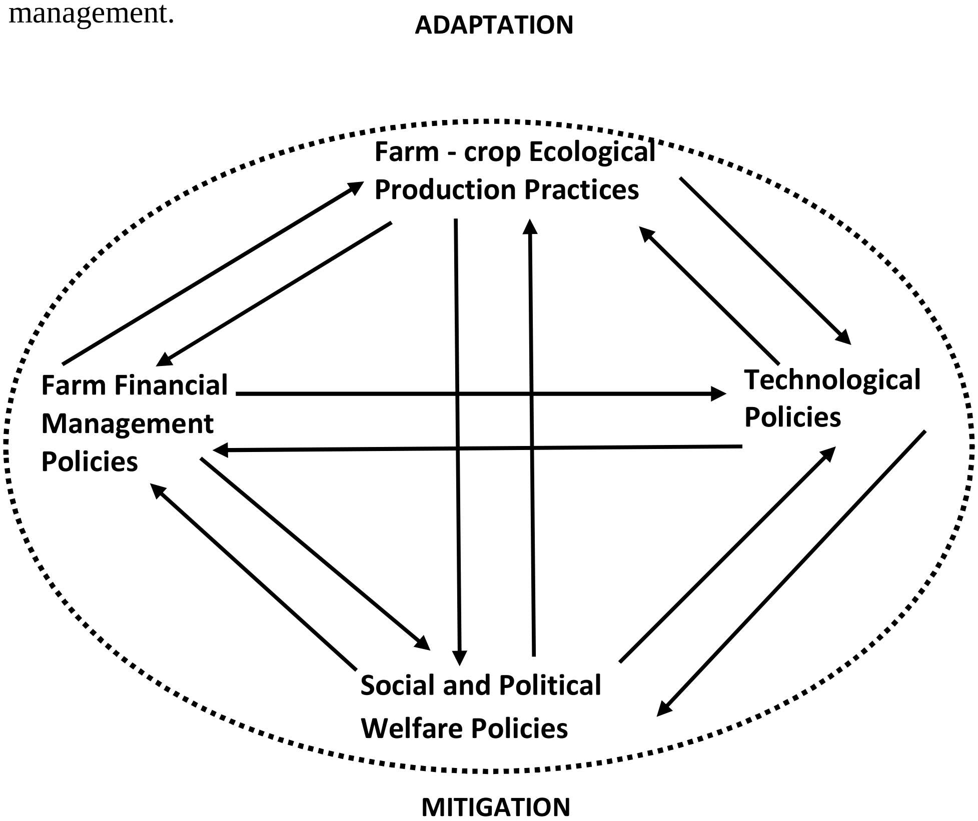


Figure 46. Interaction of the different classes of adaption policy options

Implying that adaptation options and their supporting policies should be adopted by appropriate level of governments and implemented by institutions in direct contacts with beneficiaries, if any! Examples of most of the adaptation measures have already discussed in the previous chapter. More will be appropriately discussed under the various classes of adaptation policy options.

7.3 Technology and development policies

For the challenges of climatic change on crop productivity in the Sudano-Sahel to be met, technological and developmental changes that increase crop productivity is very essential. These policies are developed through research and development programs undertaken either by the government or private organizations or Non-governmental Organizations (NGOs). Technology and developmental via research have that tendency or ability to improve crop production adaption to climatic variability and change via a plethora of proposed measures and activities. These may include:-

New crop types and varieties strengthened by a supporting policy crop research tool are very crucial. Research policies need to be in place to breed new crops types and varieties, including hybrids that respond to a range of production environments such as crops that can still produce under droughts. ICRISAT have been developing new millet and sorghum varieties and hybrids that are able to withstand severe droughts, tolerate higher temperatures and mature early, enabling the farmers to be ready to meet the challenges of climate change. Some of the pearl millet varieties and hybrids, developed from ICRISAT's germplasm, are able to flower and set seeds at temperatures more than 42^{o}C in areas such as Western Rajasthan and Gujarat in India. Improved sorghum lines have also been developed that are capable of producing good yields in temperatures of 42^{o}C, and have stay-green traits that can enhance terminal drought tolerance" (Kumar et al. 2011). These could be transferred as well to the drought stricken Sudano-Sahel of Cameroon.

Technological policies are geared towards the modernization of irrigation management systems and improving robust irrigation infrastructure for small scale water capture and storage use may be necessary for subsistence farmers to cope with climate change risks. Implementing irrigation practices involves the introduction or the enhancement of specific water management innovations including center pivot irrigation, dormant season irrigation, drip irrigation, gravity irrigation, pipe irrigation and sprinkler irrigation. New technologies could be developed by the irrigation industry to ensure irrigation efficiency. Irrigation practices could improve farm productivity and enable diversification of production in light of climate-related changes i.e. switching to crops that would otherwise not thrive in dry land agriculture. The exploitation of renewable energy technologies such as solar energy whose power could be used in pumping water from wells could also be crucial.

It is particularly common in adaption options to include activities such as the provision of information on climate change and potential impacts that may improve generally awareness or prompt consideration of adaptation (Bryant et al.2000). Adaptation thus could be promoted via policies geared towards the dissemination of information on climate change possible impacts and vulnerabilities, potential adaptation and mitigation options. The development of an information and early warning system on climate change in order to reduce the vulnerability of various social groups could also be applied in the class of technology and development policies. Climate monitoring and early warning systems whereby information on climate could be used to inform and design appropriate adaptation policies and support adaptation planning and choice of strategy are very important. Integrated advisory services and networks of early warning systems would also be of high benefit to all involved. Networks of observational stations are highly indispensable with improved climate data observations for local use, national and regional planning purposes and for global monitoring of climate change. National Meteorological Services must be encouraged and enabled to become fully integrated in research and development initiatives.

Improved practice on a large scale requires investments in capacity-building, training program and policy dialogues, knowledge management and generation, as well as dissemination of best practices, development of suitable tools and transfer of appropriate technologies. Improved climate-related services in pro-poor services require capacity to tailor and communicate information to user needs. Technical advisory services on climate risk management provided by experts with a view to enabling translation of climate information products are very much needed. The effective dissemination of modern technologies via agricultural extension services plays a key role in agricultural development (Anderson 2007). A successful agricultural adaptation requires better and clearer information combined with investments and advisory services to disseminate the information to the local farmers as well as strengthening the liaison between the bottom –down farmers and the top-up officials. Improved information systems allows for informed decisions, heightened awareness of the impacts of peoples actions and greater incentives to change crops and adopt practices to enhance management sustainability.

Extension services need to improve their effectiveness and efficiency. To be able to improve on these, government policies towards the extension services need to be improved upon since currently low income, work over load, inadequate transport facilities, and limited resources hinder their effectiveness in getting into the hinterlands.

7.4 Crop-farm production management practices

They are involved in farm operational practices that play an important role in adaptation to climate change by subsistence farmers. The policy implication to this effect is involved with the farm-level decision with respect to crop farm production techniques, land use and land systems and farm operational activities.

Increase in droughts or heat waves, increases subsistence farmers vulnerability practicing monoculture. The act of growing single crops such as millet or sorghum in the Sudano-Sahel increases subsistence farmers' vulnerability to climatic variations. Policies geared towards crop diversification provide a viable option for adaption as a wider variety of crops being planted reduces the risk of crop failure. Policies designed for the promotion of seed banks that maintain variety of seed types provides a viable opportunity for farmers to diversify. Crop switching as an adaptation option in substituting plant types, cultivars, hybrids designed for higher drought and heat tolerance has the potential of increasing farm efficiency in the face of changing temperature and moisture stress (Smith et al. 1996).

Adaptation strategies based on land use changes and crop management practices could incorporated into the policy implications with respect to climate change adaptation in the Sudano- Sahel. Most of the adaptation strategies practiced by the farmers in the region are inherent in ecological agricultural practices. These include: - crop rotation, composting, green manure, mulching, zero tillage, cover crops. These practices are have great potentials in preserving soil fertility, and concomitantly increasing the water retention ability of soils as such farmers applying such practices could be able to withstand droughts while increasing productivity (Niggli et al. 2009). Promoting rotations or intercropping with leguminous crops, the development of conservation practices such as zero tillage and putting in place of programs to scale up cover cropping could spice up the adaptation policies at farm-crop production levels. Alternatively policy proposition that stamp out some of subsistence farmers agriculture practices that are deemed unsustainable must also be adopted. Some of these negative practices are for instance slash and burns, shifting cultivation, pastoral nomadism etc that all have great impacts in land degradation.

Changing the timing of operations involving decisions that take into consideration the schedule or the timing of tilling, seeding, mulching, and harvesting all have the potentials advantage in maximizing farm productivity during the growing season and to avoid heat stresses and moisture deficiencies. This policy option again could be furnished by early warning systems and agricultural extension services earlier discussed in the technological and development policy option category above. Another crop farm management that could be incorporated includes water harvesting practices such as the indigenous Trus / Magun cultivation. In rain-fed agriculture, micro-catchments water harvesting techniques (contour bunds) are used on clay soils that harvests surface run-off by constructing low earth bunds called Trus / Magun(Osman-Elasha et al. 2006). Rain water harvested in pans is also capable of sustaining farm production through dry spells, dry seasons and seasons affected by droughts.

7.5 Farm financial management policies

Farm financial adaptation options are farm-level responses using farm income strategies (both government supported and private) to reduce the risk of climate-related income loss. Government agricultural support and incentive programs greatly influence farm financial management decisions. Policies for farm financial management adaptations involved in decisions with respect to microfinance, loans and microcredit agricultural crop insurance (weather index insurance) could be important tools in reducing the vulnerability of the poor and, in the context of climate change adaptation, providing poor people with the means to diversify, accumulate, and manage the assets needed to become less susceptible to shocks and stresses or to better deal with their impacts. Yet, these benefits may not apply to everybody (Hammill et al. 2008)

The major link between climate change adaptation and farm financial services is that financial services provide the poor access to financial capital which tends to be the least available asset for the poor. Microcredit lends funds to poor people so they can exploit their capacities for income production (job creation, enterprise growth, and increased production); it is about asset building and diversification. Returns are consumed, saved, or reinvested. Loans are also offered for non-productive purposes that may contribute to reducing vulnerability, such as emergency loans, education loans, and home improvement loans. Success stories of microfinance services have been reported in the whole of SSA by Daley-Harris et al. (2002), 970 programs in SSA offer micro-credit services reaching roughly over 8.4 million people in 2006, out of which 48 percent are women in the bottom 50 percent of the population living below their country's poverty line. Policies should therefore be put in place to encourage the establishment and spread of Micro Finance Institutions.

Speranza (2010) however reiterates that micro-credit may not be the best instrument to address the very poor due to high operational costs of MFIs, the danger of borrowers to slip into debt, the high interest rates, the exclusion of the very poor and free-riding and conflicts. Thus, there is the need to take into account the constraints and demands of the different clientele as this can limit the impacts of microcredit on smallholder subsistence farmers' income or cause negative impacts.

Since financial capital is versatile, it can be converted into other types of livelihood assets (human, social, natural, and physical capital) or it can be used for direct achievement of desired livelihood outcomes (e. g. purchasing of food to reduce food insecurity; cf. DFID 2000). Thus, an assets bundle and its combinations is positively linked with livelihood strategies – the more assets people have at their disposal, the wider the range of adaptation options available to them in their strategies to secure their livelihoods (DFID 2002 and Ellis 2000). Promoting diversification via credit access is essential in that income generating activities outside could also be boomed as a consequence thereof reducing the over-dependency in rain-fed agricultural sector. Credit access would therefore enable local farmers to buy necessary facilities like radios, or TVs to obtain weather forecast. Via credit access, farmers could easily get the necessary agricultural equipment, irrigation facilities and just to name a few that would concomitantly improve on productivity. Hence access to Rural Financial Services (RFS) can increase the livelihood assets of farmers, thereby enabling them to take measures to reduce their poverty and vulnerability to livelihood risks.

Insurance on the other hand could be another instrument used in helping the poor in managing the risk they face. Unlike state support or emergency external aid, agricultural insurance policies help farmers manage weather (drought) risk, facilitate farmers' access to agricultural credit by reducing the risk of smallholder loan default and also allow banks to expand their lending portfolio to the agriculture sector without increasing default risk (Sadler and Mahul 2011). The most common is the Weather Index Insurance that rather than basing indemnity payments on individual farm yields, index-based policies determine payments to policy holders based, for instance, on regional yields or weather data such as temperature and rainfall. This approach reduces the transaction cost involved in traditional insurance products, and because local farmers are paid regardless of their yields, this approach encourages farmers to continue producing if possible (Kryspin-Watson et al. 2006). Notwithstanding, insurance is a form of a risk management used to hedge against a loss. Agricultural insurance policy is an important component of risk management that could be incorporated into subsistence farmers adaptation strategies to climatic variability and change. However it does not replace good management techniques, sound production methods and investments in up to date technology. When coupled with these factors, agricultural insurance policies could enhance the wellbeing of the rural community and enhancing security of production.

7.6 Government national and international policy integration

Government institutions play a significant role in ensuring the safety of the public, particularly during extreme natural disasters such as flooding. Such institutions served as channels in responding to past environmental events and thus will similarly provide assistance to the local communities, especially the most vulnerable groups, in adapting to climate change (Agrawal McSweeney and Perrin 2008). The ability of local institutions to influence the impact of climate change in communities depends on the structure of local governance and local institutional arrangements.

Comprehensive social protection initiatives are required to address the risks facing the poor as a result of climate change and increasing climate variability at individual, national and international levels. At the individual level, such measures can include employment programs, cash transfers, and weather- and crop-related insurance. At the national and sub national levels, countries will need to leverage further international financial markets and develop relationships with the financial services sector to pool and transfer their risk to ensure that they will not have to significantly redirect national budgets in cases of climate shock.

The effective planning and implementing of climate change adaptation measures for agriculture will require the engagement of a core ministry in the Republic of Cameroon, such as Ministry of Economy and Finance, Ministry of Women Empowerment and the Family, the Ministry of Scientific Research & Innovation, the Ministry of Basic Education Ministry of planning, Programming and Regional Development, the Ministry of Small & Medium Size Enterprises, the Ministry of Communication, the Ministry of Environment & Nature Protection in Cameroon, the Ministry of Public Health and alongside the Ministry of Livestock Fisheries and Animal Industries, to ensure strong government support.

Secondly, the core capacities of developing country governments will need to be further developed. Such capacity building is required across a number of areas, including technical subjects such as climate forecasting and scenario planning, as well as general development topics such as governance, accountability, and empowerment of local communities. Third, adaptive and flexible management will be essential, including the capacity to monitor the results of managers' decisions and to modify actions as needed.

The interconnection between international and national policies is crucial for planning and implementing adaptations to climate change by subsistence farmers in the Sudano-Sahel. National adaptation program of action (NAPAs) of the UNFCCC provide a process for Least Developing Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage. However, most proposed NAPA-project on policy reform in integrating climate change in sectoral development plans is very much missing. Murray (2005) highlighted that poor institutional framework in many African countries foster the duplicity of services and areas of jurisdiction, the plurality of institutions as exemplified in the traditional and state laws and regulations, bureaucratic processes and corruption as the factors that interact to cause low adaptive capacity. Coordination becomes more important to implement response options that operate at the group or community level. Implement of the adaptation strategies might be done through technical services, local communities and NGOs, or by directly implementation through formulation of projects and programs. This is usually an opportunity for experts within the government and donor and international organizations to design ad formulate projects geared towards climate change adaptation and promoted via public policies and wide-scale public support.

The core programs of international development agencies and donors must encompass the impacts of climate change as it affects poverty, food security, and economic development in developing countries. Development agencies must ensure that climate issues are internalized in their poverty reduction programs. This approach requires developing tools and methodologies, training, and raising awareness of senior management and staff. It may also involve modifying their own institutional processes to ensure that climate change vulnerability in developing countries is addressed in all of their development work (Sperling 2003). Although funds for climate change adaptation and mitigation strategies for developing countries are already available, securing access to these funds poses a challenge for developing countries.

7.7 Conclusion

From the foregone account, the importance of subsistence agriculture in the Sudano-Sahel of Cameroon cannot be underestimated, for it plays an important role on the livelihood of the population. Large populations based in the rural areas depend solely on rain-fed agriculture for their subsistence with poverty levels stagnating and societal resilience to climatic variations not improving. Observed climatic trends have been changing with their variations very unambiguous, as rainfall shows a significant negative trend and temperature the reverse. These have all been indicated by the increase in the frequency and the duration of droughts and evident in the agricultural drought analyses of the 9-months for Maroua, Garoua and Ngaoundere respectively. However, still on the results of the agricultural drought analysis via SpI, the trend lines show the presence of water, which tend to counteract the fact that the Sahel is a totally dry area of land.

The recent impacts of changing climate trends on yields show variability between millet and sorghum, indicating the influence of various climatic variables on different crops. Millet and sorghum yields in the Sudano Sahelian region of Cameroon have been affected by climatic variability as evident, during the Sahelian droughts of the 60s, 70s, 80s and 90s. Variability in the climate of the growing season between May and August appeared to have contributed to the differences in the yield trends for both millet and sorghum. The result of the regression analyses in determining what actually impacts the yields of the subsistence crops in this study highlights that millet and sorghum crop yields are influenced by other external factors different from climatic variability. In the case of millet, increase in harvested areas turned to increase crop yields, but this wasn't the case for sorghum. Based on the result of the remote sensing analysis, factors other than climatic factors have a role to play in agricultural crop productivity in the Sudano-Sahel of Cameroon. With a population growth rate at 2.6%, there is the tendency of exertion of pressure on the productive land area. Settlement patterns have changed, based on the availability of fertile zones, thus leading to more barren areas of land.

Subsistence farmers no doubt have been operating in marginal lands and most have already adopted some coping strategies in harsh climatic conditions that have prevailed over the past years. These indigenous adaptations range from the changing in planting dates, and crop varieties, movement to from rural to urban areas, increment in cultivated lands, irrigation and soil conservation practices, the use of local indicators and switching from crops to livestock. Despite these perceived adaptation strategies, adapting to climatic change is a costly venture and most of the factors that hinder subsistence farmers' adaption to climatic change could be coined under the banner of poverty. A plethora of findings have already emerged that resonate with a battery of earlier literature on subsistence agriculture and options for adaptation.

Adaptation by subsistent farmers should go beyond the above mentioned practices, else climatic variation and change will continue to increasingly have devastating impacts on subsistent farmers in the Sudano-Sahel of Cameroon. Adaptive responses tend to be reactive, and there is little evidence of planning. Policy makers should pay particular attention on the role of local and indigenous knowledge when adaptation is concerned. These are some of the type of experiences passed down from generation to generation and offer very invaluable information regarding coping options that would not be acquired through other channels. More importantly, special considerations should also be given in tackling the highlighted constraints perceived by subsistence farmers towards adaptation.

An integrated approached would seemingly pay-off aimed at protecting the poor against the devastating outcomes of crop failure via climatic uncertainties. The effective implementation of an agenda for climate change adaptation will require mainstreaming climate change and adaptation into development planning, reforming climate-related governance and institutions, and undertaking massive new investments. Stable and supportive policies should be implemented to improve risk management of subsistence farmers. Polices that tend to strengthen and support on going indigenous knowledge on climate change adaptation employed from time in-memoriam. These policies towards the farm-crop ecological production practices, technological development policies, farm financial management policies, social and political welfare policies. The initiatives include improved information collection, use and collection, improvement in extension services, exploration of the green and carbon market, diversification, enhancing social protection. Furthermore all stakeholders should be involved when considering measures to reduce the adverse effects of climate change. The government, civil societies, private sectors, and above all the local communities, local farmers associations, non-governmental organizations (NGO) and the media should all actively participate and be more involved in promoting adaptation.

Climate change has an impact on subsistence crop production in the Sudano-Sahelian zone of Cameroon. By employing the top-down approach focusing on the biophysical aspects of vulnerability via the analyses of the climatic trends and their impacts on yields of subsistence crops, population influence on agricultural systems and concomitantly the bottom-up approach in paying emphasis on local communities and aspects of vulnerability and making use of indigenous knowledge relevant to community level responses. Integrating both approaches could play a vital role in determination and promotion of integrated adaptation options to climatic variability and change.

7.8 Recommendation

A series of coherent and integrated recommendations in safeguarding crop productivity and the livelihood of subsistence farmers, while implementing adaptation and mitigation measures for climate change, are based on the concepts and scope of activities identified in the previous chapters' write-ups.

- The Value of Local Knowledge:

  The current strategies in used by the subsistence farmers should be considered in the countries national adaptation plan of action. For local and indigenous knowledge serve as a sink and could act a springboard in the formation strategies that could aid local farmers.

- Research and Education

  Through research, new crop varieties and hybrids that are able to withstand severe droughts, tolerate higher temperatures and mature early, could enable the farmers to be ready to meet the challenges of climatic variability and change in the Sudano-Sahel. New technologies, such as irrigation techniques, early warning systems could be developed. Education of the rural farmers is very much imperative if they need to adapt to climate change.

- Agricultural extension Services: A successful agricultural adaptation requires better and clearer information combined with investments and advisory services to disseminate the information to the local farmers as well as strengthening the liaison between the bottom–down farmers and the top-up officials. Adequate extension information services to ensure that farmers receive up-to date information about climatic patterns in the forthcoming season so that they can make well informed decisions about their planting dates. They could also play a role in land use changes and crop-farm management practices of subsistence farmers that could play a role in adaptation and concomitantly mitigation of climate change.

- Governments and International Organizations have a very big role to play with regards to the adaptation of subsistence farmers to climate change. The effective implementation of an agenda for climate change adaptation will require mainstreaming climate change and adaptation into development planning, reforming climate-related governance and institutions, and undertaking massive new investments. Stable and supportive policies should be implemented to improve risk management of subsistence farmers and would require the engagement of core ministries in the Republic of Cameroon. The core programs of international development agencies and donors must encompass the impacts of climate change as it affects poverty, food security, and economic development of the rural poor.

- Financial Support: Financing of the rural area by setting up suitable financial systems that will allow smallholders subsistence farmers to have access to credit. These policies that improve household welfare as well as access to credit are also a priority for both short- and long-term adaptation measures.

"If agriculture has a final frontier; it is the Sudano-Sahel and Africa in general. This is one of the only places in the world where the farming potential has barely been scratched and the dependency on rain-fed agriculture makes it very vulnerable to climatic variability and changes. African agriculture is hinged to the rains, has less fertilizer usage, less seed research, less mechanization, less rural financing, fewer paved farm-to-market roads than any other region in the world" (Roger Thurow, Wall Street Journal 27 May 2008).

7.9 Outlook

The work described in this thesis contributes to the present day quest for climate change adaptation strategies by subsistence farmers at the local level. A couple of ideas have been presented for future research within the context of the research framework. Since the subsistence farmers are the most susceptible to the impacts of climate change in the Sudano-Sahel as they hinge on rain-fed agriculture for their subsistence, and with subsistence farmers' adaptation constraints coined under the canopy of poverty, the author thus sees financial and technical resource as the key that could facilitate and smooth subsistence farmers' adaptation to climate change in the Sudano Sahel. Microfinance institutions (MFIs) from the author's viewpoint provide a win-win partnership with climate change adaptation by subsistence framers.

Historically, the role of Microfinance Institutions (MFIs) has been precisely to respond to the demand for financial services from poorest individuals and thus able to serve a market segment neglected by basic financial entities and traditional financial banks. Considering the premise that microfinance access helps poor people out of poverty, and considering that major premise that climate change is indeed a threat which the poor are acutely vulnerable. Then one could conclude that microfinance is in fact a valuable tool with the capacity to reduce the vulnerability of the poor farmers in the Sudano-Sahel.

The task therefore would be in the designing of MFIs products that promote adaptation. The researcher has sidelined microcredit and loans; climate based insurance, green microfinance as some products that warrant research in their adoption to climate change adaptation at the local level. Another aspects pertaining to improving subsistence farmers' adaptation to climatic change in the Sudano-Sahel that the research warrants further research is the development of voluntary sustainability standards in the farming practices of the locals. Setting criteria and indicators of best climate practices that farmers can implement to demonstrate their efforts to mitigate and adapt to climate change. These might enable farmers to perform and participate in the global voluntary carbon market via service conditions that incentivize sustainable resource stewardship and reinforcing longer- term vulnerability reduction gains. This aspect is thus opened for further research.

ANNEXES

Annex 1. Questionnaire on climatic variability and change impacts on crop production in northern Cameroon, options for adaptation

Dear Participant,

I am currently writing my PhD thesis at the Chair of Environmental Planning at the Brandenburg University Technology Cottbus, Germany.

Climate change is real and its impacts would add significantly to the development challenges of ensuring food security and poverty reduction in most Sub-Saharan African countries as a whole and Cameroon in particular. The information provided by you in this survey about your family activities will contribute to the better understanding of the impacts of climatic variability and change on subsistent crop production in the Sudano-Sahel region of Cameroon and some options for adaptation.

Thank you very much for your time.

1. Household Information

Name and Surname :(Optional)

Gender: M ☐ F ☐

Marital Status: S ☐ M ☐

Household Number : <1 ☐ 1-4 ☐ 5-8 ☐ 9-12 ☐ 13+ ☐☐☐

Do you have any other source of income other than agriculture? Yes ☐ No ☐

If yes, please specify.

2. Agricultural Systems

Agricultural type practiced. Rainfed ☐ Irrigation ☐

2.1 Farming Types

Crop Farming ☐

Pastoral Farming ☐

Mixed Farming (Agro pastoral farming) ☐

Nomadic pastoralism ☐

Other, please specify:

2.2 Farming Systems used

Multiple cropping	☐
Irrigation	☐
Monoculture	☐
Fertilizer use	☐
Others, please specify:	

2.3Crops/Cattle Types

Millet	☐
Sorghum	☐
Maize	☐
Groundnut	☐
Cattle Types : Sheep ☐ Goats ☐ Cows ☐ Horses ☐ Donkey ☐	
Others, please specify:	

2.4 Have there been changes in crop production over the past 40 years?

Increase ☐ Decrease ☐ No change ☐

Please Specify reasons for the above responses.

Increases:	☐
Decreases:	☐
No Changes:	☐

3. State of Knowledge of farmers on Climatic Variability and Change:

3.1 Temperature

3.1.1 Have you noticed any long-term changes in the mean temperature over the past 40 years?
Yes ☐ No ☐

3.1.2 Has the number of hot days changed?

Increased ☐ Decreased ☐ No changes ☐

Please Specify reasons for the above responses.

Increased:

Decreased:

No Changes

3.2 Rainfall

3.2.1 Have you noticed any long-term changes in the mean rainfall over the past 40 years?
Yes ☐ No ☐

3.2.2 Has the number of rainfall days changed?

Increased ☐ Decreased ☐ No changes ☐

Please Specify reasons for the above responses.

Increased:

Decreased:

No Changes

3.3 What could account for the changes in crop production over the past year?

Climatic changes ☐ Other Factors ☐ Don't Know ☐

3.4 What is climatic variable that strongly affects you agricultural production?(Depending on 3.3)

Extreme temperatures	☐
Weak rainfall	☐
Variation in rainfall	☐
Change in the Start of the rainy season	☐
Others, please specify:	

4. Adaptation Measures

4.1 Have you adapted to try to adapt to current climatic variation?

Yes ☐ No ☐

4.1.2 If yes, what are some the adaptation strategies you have so far adopted?

A. Change of planting dates		☐
B. Change crop varieties		☐
C. Movement to different sites		☐
D. Switching from crops to livestock		☐
E. Switching from Livestock to crops		☐
F. Reduction in number of livestock		☐
G. Reduction in cultivated land		☐
H. Increase in land area cultivated		☐
I. Use of water conservation techniques		☐
J. Implementation of Soil conservation techniques		☐
K. Use of irrigation		☐
L. Use of shades and shelters		☐
M. Rural urban migration		☐
N. Use of insurance		☐
O. Search for off farming jobs		☐
P. Religious beliefs or prayers		☐
Q. Change use of chemical fertilizers, pesticides and insecticides		☐
R. Other adaptations techniques		☐
S.		☐

4.2 What are some of the constraints in adapting to Climatic variability and change?

A. Limited awareness or information	☐
B. Poverty	☐
C. Low level of technology	☐
D. Shortages of labour inputs	☐
E. Poor soils	☐
F. Lack of water	☐
G. Shortages of land for cultivation	☐
H.	☐
I.	☐
J.	☐

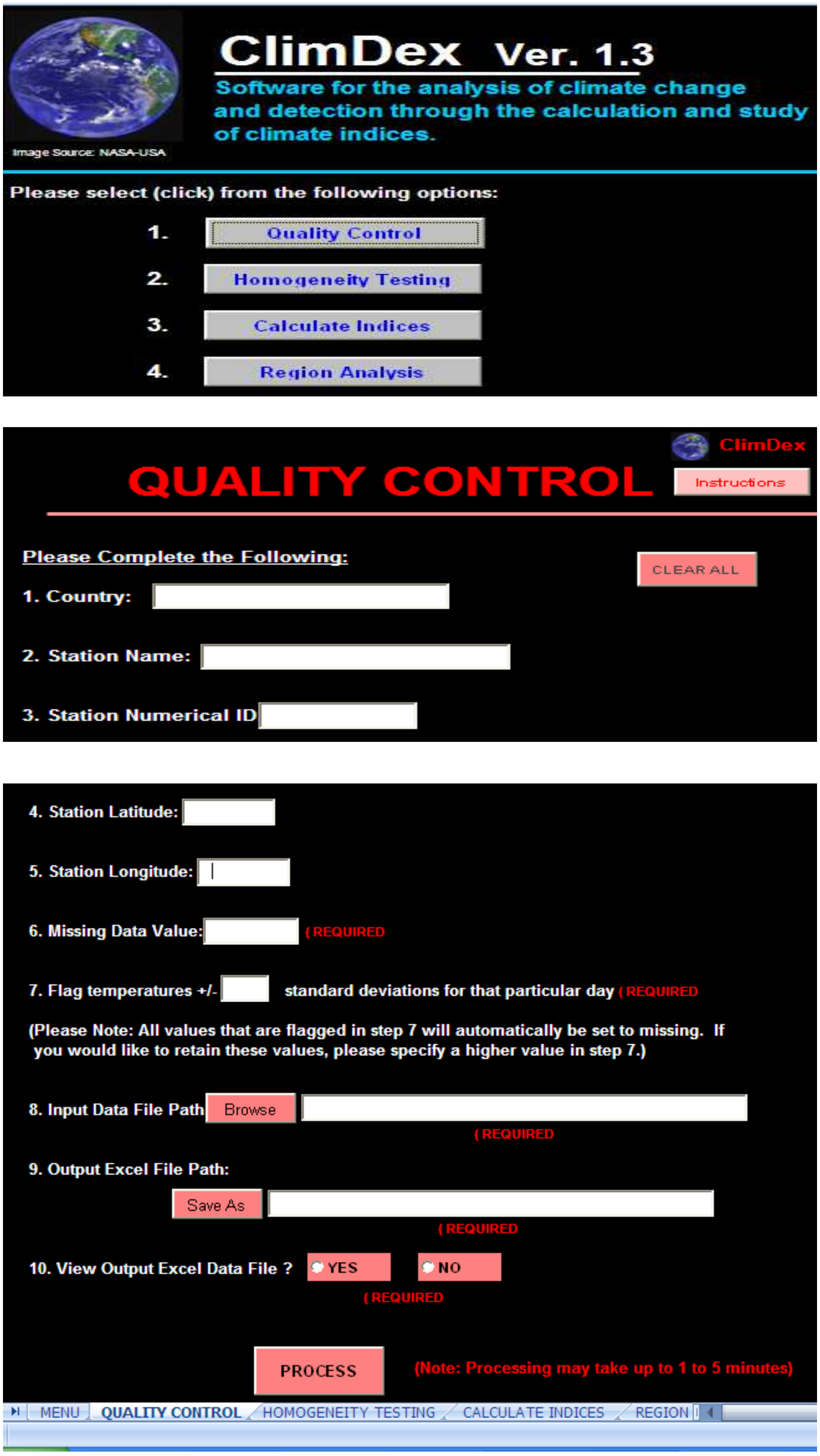
4.3 What other adaptation options could you recommend for policy implications?

A.	
B.	
C.	
D.	
E.	
F.	

Thank you very much for answering this questionnaire!

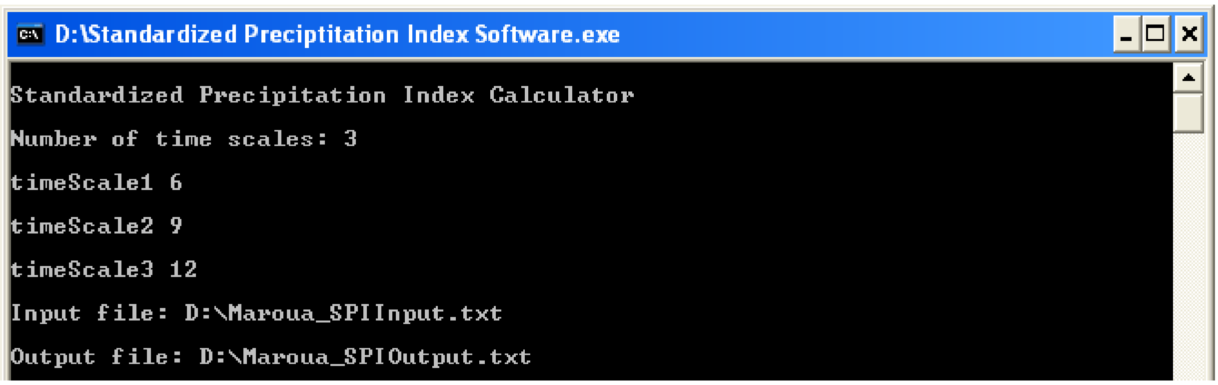
If you wish to be informed of the results of this survey please indicate either your email address, telephone number or postal address below.

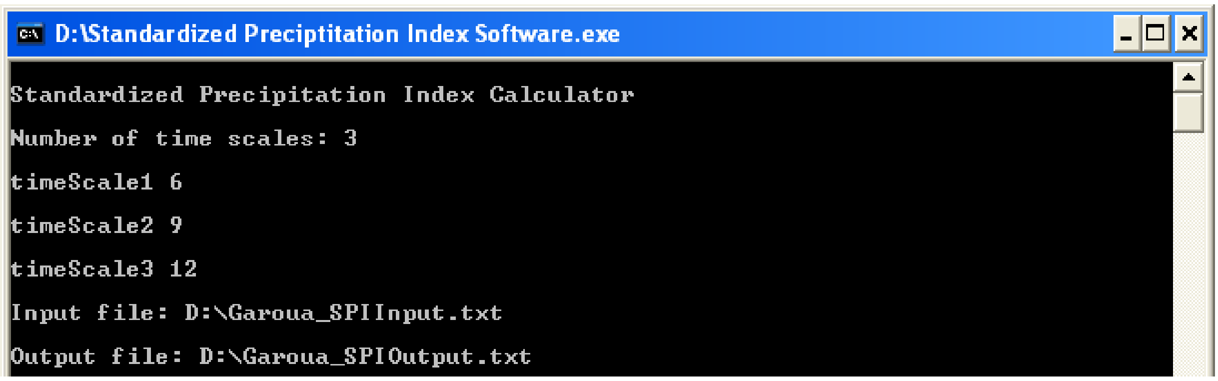
Annex 2. Data quality control via ClimDex 2.0 Screenshot of ClimDex version 1.3

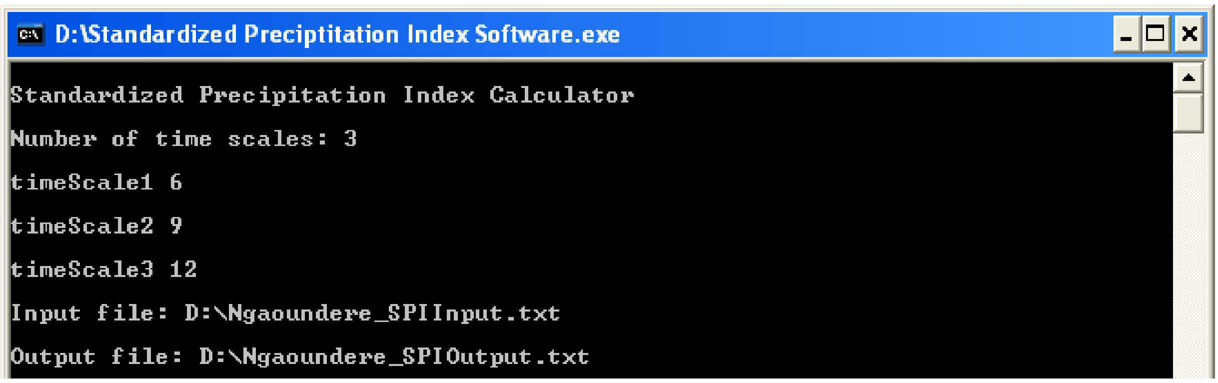


(Source: Climdex 2011)

Annex 3. SPI Dialogue box for analyses. Screen shot of the SPI dialogue box applied for Maroua, Garoua and Ngaoundere based on 3 time scale periods of 6, 9 and 12-months SPI from 1961-2006







Annex 4a. Sample Input data file format with year, month, and monthly precipitation values for study region

Maroua_SPIInput -...

Datei Bearbeiten Format Ansicht ?

1961	1	0
1961	2	63
1961	3	0
1961	4	297
1961	5	628
1961	6	610
1961	7	526
1961	8	984
1961	9	390
1961	10	107
1961	11	0
1961	12	0
1962	1	192
1962	2	5
1962	3	0
1962	4	241
1962	5	384
1962	6	72
1962	7	648
1962	8	698
1962	9	231
1962	10	275
1962	11	1
1962	12	0
1963	1	0
1963	2	32
1963	3	1
1963	4	63
1963	5	138
1963	6	457
1963	7	694
1963	8	473
1963	9	251
1963	10	200
1963	11	0
1963	12	0

Garoua_SPIInput ...

Datei Bearbeiten Format Ansicht ?

1978	1	3
1978	2	13
1978	3	4
1978	4	136
1978	5	872
1978	6	640
1978	7	401
1978	8	463
1978	9	521
1978	10	28
1978	11	0
1978	12	0
1979	1	2
1979	2	1
1979	3	128
1979	4	171
1979	5	278
1979	6	1617
1979	7	735
1979	8	769
1979	9	370
1979	10	550
1979	11	0
1979	12	1
1980	1	1
1980	2	4
1980	3	38
1980	4	88
1980	5	124
1980	6	642
1980	7	488
1980	8	532
1980	9	479
1980	10	220
1980	11	17
1980	12	0

Ngaoundere_SPII...

Datei Bearbeiten Format Ansicht ?

2004	1	2
2004	2	0
2004	3	98
2004	4	646
2004	5	674
2004	6	988
2004	7	874
2004	8	1393
2004	9	1010
2004	10	498
2004	11	270
2004	12	1
2005	1	1
2005	2	3
2005	3	76
2005	4	643
2005	5	702
2005	6	613
2005	7	1258
2005	8	1140
2005	9	782
2005	10	321
2005	11	278
2005	12	7
2006	1	0
2006	2	3
2006	3	2
2006	4	459
2006	5	1005
2006	6	538
2006	7	819
2006	8	1382
2006	9	665
2006	10	723
2006	11	31
2006	12	9

Annex 4b. Sample output 6, 9 and 12-months SPI computed values. Columns 4 represent computed 9-months SPI values for study region

Maroua_SPIInput - Edi...

Datei Bearbeiten Format Ansicht ?

1961	1	-1.47	2.61	2.34
1961	2	-1.10	3.05	2.39
1961	3	-0.56	1.03	2.39
1961	4	0.87	-0.75	2.64
1961	5	1.87	0.82	3.49
1961	6	1.84	1.61	2.20
1961	7	1.17	1.14	0.25
1961	8	1.43	1.49	0.93
1961	9	1.48	1.55	1.37
1961	10	1.37	1.56	1.54
1961	11	0.62	1.48	1.54
1961	12	0.19	1.48	1.54
1962	1	1.29	1.62	1.80
1962	2	0.70	0.92	1.69
1962	3	1.11	0.58	1.69
1962	4	1.12	1.21	1.56
1962	5	1.48	1.13	1.23
1962	6	0.41	0.33	0.36
1962	7	-0.33	0.06	0.54
1962	8	-0.24	0.08	0.06
1962	9	-0.53	-0.20	-0.25
1962	10	-0.39	-0.29	0.06
1962	11	-0.87	-0.27	0.07
1962	12	-0.18	-0.27	0.07
1963	1	0.10	-0.41	-0.33
1963	2	0.19	-0.84	-0.27
1963	3	1.13	-0.16	-0.26
1963	4	-0.43	-0.19	-0.59
1963	5	-0.58	-0.38	-1.11
1963	6	-0.13	0.25	-0.37
1963	7	-0.26	-0.27	-0.23
1963	8	-0.67	-0.65	-0.59
1963	9	-0.94	-0.93	-0.64
1963	10	-0.60	-0.80	-0.81
1963	11	-0.52	-0.83	-0.81
1963	12	-0.80	-0.83	-0.81

Garoua_SPIOutput - Editor

Datei Bearbeiten Format Ansicht ?

1978	1	-0.06	-0.19	-0.11
1978	2	-0.39	0.01	-0.09
1978	3	-1.78	0.19	-0.09
1978	4	-0.23	-0.16	-0.25
1978	5	1.51	0.76	0.64
1978	6	1.12	0.50	0.98
1978	7	0.68	0.65	0.47
1978	8	0.09	0.12	-0.15
1978	9	0.14	0.11	-0.37
1978	10	-0.33	-0.40	-0.42
1978	11	-1.32	-0.45	-0.43
1978	12	-1.75	-0.41	-0.42
1979	1	-1.73	-0.37	-0.45
1979	2	-1.21	-1.31	-0.47
1979	3	-1.21	-1.53	-0.28
1979	4	0.73	-1.29	-0.20
1979	5	0.00	-1.02	-1.29
1979	6	2.03	1.47	0.42
1979	7	2.27	2.22	1.02
1979	8	2.03	2.03	1.39
1979	9	1.47	1.57	1.08
1979	10	1.62	1.79	1.77
1979	11	1.95	1.76	1.76
1979	12	0.50	1.66	1.76
1980	1	0.28	1.58	1.74
1980	2	0.22	1.93	1.74
1980	3	0.83	0.50	1.67
1980	4	-0.51	0.11	1.49
1980	5	-1.72	-0.87	1.39
1980	6	-0.63	-0.19	-0.08
1980	7	-0.92	-0.97	-0.57
1980	8	-1.15	-1.13	-0.92
1980	9	-1.04	-1.01	-0.67
1980	10	-1.07	-1.20	-1.23
1980	11	-0.67	-1.21	-1.20
1980	12	-0.94	-1.24	-1.20

Ngaoundere_SPIOutpu...

Datei Bearbeiten Format Ansicht ?

2004	1	-0.21	-0.72	-0.96
2004	2	-0.88	-1.19	-1.07
2004	3	-0.92	-0.75	-1.05
2004	4	0.48	0.14	-0.45
2004	5	0.29	-0.45	-0.93
2004	6	1.08	0.63	0.05
2004	7	0.90	0.75	0.52
2004	8	1.61	1.57	0.97
2004	9	1.61	1.52	1.29
2004	10	1.45	1.60	1.49
2004	11	2.00	1.78	1.75
2004	12	1.64	1.84	1.75
2005	1	2.05	1.65	1.78
2005	2	1.40	2.00	1.78
2005	3	1.04	1.58	1.80
2005	4	1.38	2.04	1.72
2005	5	0.30	1.24	1.94
2005	6	0.18	0.78	1.45
2005	7	0.92	1.23	2.03
2005	8	1.24	1.21	1.73
2005	9	1.07	0.96	1.26
2005	10	0.70	0.84	1.06
2005	11	1.16	1.07	1.04
2005	12	1.28	1.15	1.05
2006	1	0.85	0.95	1.07
2006	2	0.40	1.17	1.08
2006	3	0.03	1.10	1.01
2006	4	0.48	0.54	0.76
2006	5	0.47	0.56	1.22
2006	6	0.10	0.37	1.09
2006	7	0.06	0.44	0.57
2006	8	0.88	0.86	0.90
2006	9	0.73	0.53	0.66
2006	10	1.09	0.91	1.14
2006	11	0.84	0.85	0.83
2006	12	1.05	1.02	0.83

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Annex 5. Quantification and valorization of the potentials of SSA Agriculture in Climate Change Adaptation and Mitigation

Estimated Economic Mitigation Potential by agricultural practices in the regions in SSA based on B1 Scenario by 2030 at 0€ - 15€ per ton of Carbon dioxide equivalent ($MtCO_2e/yr$), based on the B1 Scenario. The technical mitigation potential from agriculture is greatest in the East, West and central Africa with potentials of 109, 60 and 49 $MtCO_2e/yr$. respectively at prices of 0€ - 15€ per ton of Carbon dioxide equivalent ($MtCO_2e/yr$).

Region	**Cropland Management**	**Grazing land Management**	**Restoration of organic soils**	**Restoration of degraded land**	**Other practices**	**TOTAL**
East Africa	28	27	25	13	15	109
Central Africa	13	12	11	6	7	49
Southern Africa	6	5	5	3	3	22
West Africa	16	15	14	7	8	60
	63	59	55	29	33	**240**
Total	(26%)	(25%)	(23%)	(12%)	(14%)	(100%)

(Source: Adapted from Smith et al. 2008).

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